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Quality Building Projects Through Constructability

by

Michael Deen Miller, B.S.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 1998

Dedication

To my parents, Roy and Jacque, my sister, Jennifer, my brother, Brian, and my wife, Andrea.

Acknowledgements

I would like to thank all my professors whose teachings lead me in the direction of this thesis. In particular, Dr. Richard L. Tucker and Dr. John D. Borcherding whose ideas and leadership made this thesis a reality. I would also like to thank Mr. Ray Martin, who shared his field experiences and construction improvement ideas with me. Finally, I would like to thank my wife Andrea, who encouraged me and supported me during countless hours at the computer.

December 1, 1998

Abstract

Quality Building Projects Through Constructability

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The University of Texas at Austin, 1998

Supervisor: Richard L. Tucker

In the future, customers of the construction industry will continue to demand projects that cost less, finish faster, and provide higher standards of quality. To meet these objectives, the construction industry must rely on quality improvement strategies like Constructability. Constructability increases the potential for project success by expanding the role of construction expertise into front-end planning and design to anticipate and minimize problems during field operations. Despite prior success on industrial projects, much of the construction industry, particularly the building sector, has not explored or implemented the ideas behind constructability. This thesis attempts to support the use of Constructability as a potential avenue for improvement in building projects by analyzing constructability-related data from 58 projects and presenting constructability observations made during a field study.

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Chapter 1: Introduction

1.1 Purpose

The purpose of this thesis is to support the use of "Constructability" as a potential avenue for improvement in building projects. To date, the majority of constructability implementation and research has focused on heavy industrial construction with little effort directed at the building sector. The intent of this thesis is to focus on building projects and support constructability as a logical improvement tool having significant savings potential and influence on all phases of the construction process.

Previous construction management experience, exposure to the Construction Industry Institute's (CII) research, and graduate class work led to interest in constructability and the desire to meet the following objectives.

- Review the use of constructability as a continuous quality improvement tool.
- Discover the applicability of constructability on building projects.
- Investigate constructability's affect on building project performance, specifically cost growth, schedule growth, and safety use.
- Investigate constructability as a catalyst for continuous improvement, specifically showing its influence on pre-project planning and team building.
- Provide further analysis of the CII Benchmarking and Metrics (BM&M) Database.

1.2 SCOPE

The scope of this thesis is limited to the application of constructability on building projects. The data presented in this thesis includes 58 projects from CII's BM&M Database and constructability observations discovered during a field study. Data from the CII BM&M Database represents CII member company projects from the 1995 to 1997 timeframe, while the constructability observations were made during the summer of 1998 from a non-CII member project. Statistical analysis of data from the 58 building projects and documentation of observations from the field study are used to prove the advantages of constructability use on building projects.

1.3 THESIS ORGANIZATION

Chapter 2 of this thesis covers the background literature review. It looks at the relationship of Total Quality Management and Constructability and presents key success factors in both areas. In addition, it provides the rationale behind constructability as an influential quality improvement tool for the Construction Industry.

Chapter 3 discusses the methodology employed for this thesis. It explains how the literature review combined with observations from a field study and results from data analysis are used to develop the conclusions. The chapter also contains the background information on the project of the field study and on CII whose BM&M data was used in the data analysis.

Chapter 4 describes the data used from the BM&M Database. The first part of the chapter presents the entire BM&M Database to provide the reader a perspective of where the thesis data originated. The second part of the chapter shows the particulars of the 58 building projects.

Chapter 5 is the data analysis and results from the 58 building projects. It briefly describes the analysis process and then presents analysis and corresponding results.

Chapter 6 presents the observations discovered during the field study. The chapter is divided into three improvement categories: Design and Construction Coordination, Suggested Field Improvements, and Management Techniques. Each improvement opportunity is summarized and then commentary follows to provide specific background from the project.

Chapter 7 summarizes the conclusions found from the literature review, data analysis, and field study. In addition, recommendations for further research opportunities are listed.

Chapter 2: Background

As early as the late 1970's, corporations involved with the Business Roundtable started voicing concern about the rising cost of construction. With their large investments in the construction industry as the initiators, financiers, and end users of construction projects, they commissioned the Construction Industry Cost Effectiveness Project to begin researching deficiencies in the construction process. A finding from Report A-6 called Modern Management Systems, November 1982, states

> The construction industry has been criticized, to a large extent justifiably, for its slow acceptance and use of modern management methods to plan and execute projects. Many people both inside and outside the industry view this as a primary cause of serious delays in schedules and large cost overruns that have plagued the industry in recent years. Yet there is no lack of modern cost-effective management systems that can provide managers with all the controls they need.

Even though it has been almost 20 years and competition, legal involvement, and project complexities have increased, the construction industry in general is still largely unaware of the potential positive impacts of modern management methods and continues to function inefficiently under traditional practices.

Some companies, however, have recognized the need to change and are turning to management methods based on Total Quality Management (TQM). Although developed around the Manufacturing Industry, TQM principles have developed into construction-based improvement tools and have helped control the construction process to meet performance objectives like cost, schedule, safety,

and quality. In fact, industry sponsored research, such as that conducted by the Construction Industry Institute (CII), is having extensive applications on early project planning, team building, and design and construction coordination, verifying the trend toward continuous quality improvement efforts (see Chapter 3 for an explanation of CII). Owners attempting to align construction endeavors with business goals make it imperative for engineering and construction companies to implement process improvement tools as normal construction practice to meet the requirement for faster, cheaper, better quality projects.

This thesis focuses on investigating "Constructability" as one of the more influential continuous quality improvement tools capable of reducing costs and schedule, improving teamwork, and enhancing planning effectiveness. The remainder of this chapter is devoted to a general discussion of TQM and its successes, defining "Constructability" and showing its alignment with TQM principles, and understanding the rationale and benefits for the use of constructability on building projects. The remaining chapters of this thesis are devoted to confirming Constructability's positive influence on project success by analyzing constructability related data from 58 building projects contained in the CII Benchmarking and Metrics (BM&M) Database and then presenting constructability observations discovered on typical building project.

2.1 Total Quality Management

"Total Quality Management (TQM) is the integration of all functions and processes within an organization in order to achieve continuous improvement of

the quality of goods and services" (Swift et al. 1998). This management philosophy is a never-ending journey (CII 1992) of process evaluation and improvement through teamwork, fact-based decision making, and employee empowerment to ensure customer satisfaction. Instead of final product quality inspections, TQM front loads quality by increasing planning efforts and using proactive process monitoring to forecast outputs and prevent future problems from occurring (Gevirtz 1994). TQM views every product, process, or service as an opportunity to improve and only through consciously seeking and exploiting these opportunities at all levels can an organization become successful (Swift et al. 1998).

2.2 TQM Success in Manufacturing

Manufacturing companies using TQM have found that product delivery times can be drastically reduced with the use of multi-disciplined teams from the onset of a project. Traditionally, manufacturing had inherent conflicts between department functions that operated without clear corporate and interdepartmental goals. Marketing wanted maximum sales, purchasing wanted lowest price, engineering wanted advanced and reliable designs, manufacturing wanted mass production, and quality wanted products that meet specifications and did not cause customer complaints. However, by improving teamwork and increasing up-front planning efforts, manufacturing has been able to reduce development time and increase the potential for project success (Gevirtz 1994).

Using TQM principles, many manufacturing companies were able to develop highly productive atmospheres for their product development process teams. Successful companies dedicated personnel full-time to projects because it ensured the necessary resources were available early on in the process when important decisions about products are made. Early involvement of the various manufacturing disciplines on the team ensured critical concerns and opinions were understood from the beginning. With common objectives, teams focused on meeting all key performance and quality needs for a project and the traditional, unhealthy departmental conflicts were eliminated. The increased contact of team members through regular team meetings allowed understanding and appreciation of the various disciplines and fostered communication and the exchange of ideas. Under the watchful eyes of a project leader, team members were coached through the entire product delivery process. The team leader maintained final responsibility, but gave team members the authority and freedom to become involved in improvement activities within the confines of project objectives. In addition to individual team improvement, manufacturing found it important to have the ideas, technological breakthroughs, discoveries, and solutions to problems shared between teams within an organization.

The idea of teamwork in a continuous quality improvement environment has ensured the survival of many manufacturing companies. They have refocused their priority on customer satisfaction and delivered products faster and cheaper than ever before. By fostering teamwork at the onset of a project, quality is built into products from the beginning, and costly corrections further down the

development cycle are eliminated. "It is more expensive to fix problems farther along in a development cycle and/or after the product has been manufactured than it is to prevent them." The 1-10-100 rule of manufacturing expresses the ratio of costs to prevent a defect before it occurs, to correcting it before it has reached the customer, to correcting it after it has reached the customer (Gevirtz 1994). Improved teamwork and up-front investments in project planning have allowed manufacturing companies to provide cheaper, faster, and better quality products that have increased their profits and market share and kept overall project costs down.

2.3 CONSTRUCTABILITY: AN OPPORTUNITY FOR IMPROVEMENT

Although TQM grew out of the manufacturing industry, multi-discipleine teams, planning, common objectives, full-time personnel, effective communication, empowerment, and lessons learned are useful in engineering and construction. According to 1990 research conducted by the CII, "Companies must institute TQM or become noncompetitive in the national and international construction and engineering markets within the next five to ten years" (CII 1990). The impact of this statement is not in the timing, but the fact that survival of the engineering and construction industry rests on the ability of the industry to grasp the concepts of this new management philosophy and exploit the opportunities it presents.

The multi-discipline team concept that manufacturing has implemented so well to recognize cost savings and decrease product delivery times has existed for

years in engineering and construction. However, problems have developed over time that have alienated the various functions of the project delivery process and further supported the use of less efficient building practices. The increased complexity and cost of today's construction projects have created an environment heavily influenced by legal issues which has further hindered the effective use of a project team approach (Borcherding 1997). However, the utilization of the construction-based quality tool called Constructability, provides a forum to improve teamwork, planning, and design and construction coordination.

Constructability expands the role of construction expertise into front-end planning and design in order to anticipate potential problems in field operations before they occur. CII defines constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives." By obtaining the capabilities, implementing the ideas through awareness and training, applying the concepts and procedures, monitoring and evaluating effectiveness, and documenting lessons learned, organizations using constructability can benefit from developing teams that look at "how to build" and "how decisions effect construction." CII views constructability "as an essential element to any continuous improvement program" (CII 1986).

The traditional approach where planning, design, and construction efforts are completed by separate organizations minimizes the integration of a true project team. Like the manufacturing community discovered with its product development time, the construction industry must recognize that the ability to

influence a construction project is greatest during planning and diminishes exponentially into field operations. Figure 2.1, the Cost Influence Curve, similar to the manufacturing 1-10-100 rule, illustrates the costs to make changes on a project are low early on while influence is high versus the drastic increase in costs and limited influence on project success later on, once construction gets underway (CII 1986 3-1).

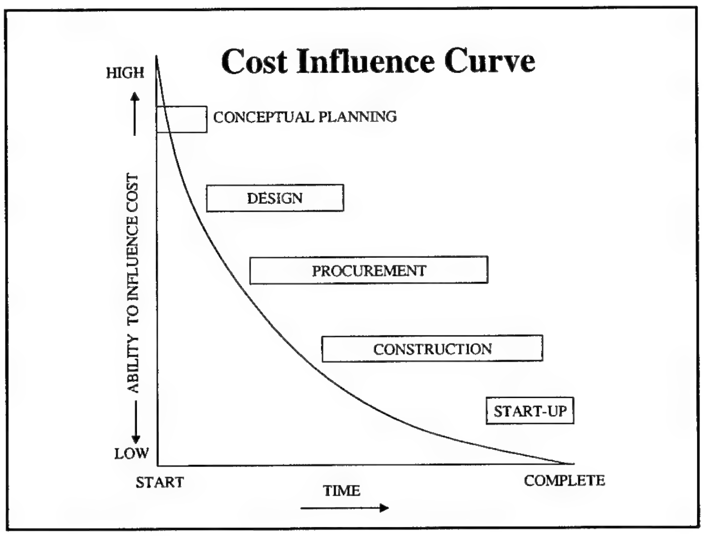


Figure 2.1 – The CII Cost Influence Curve

The word "Constructability" is not unfamiliar in the industry, but the extent of its application has been narrowed to identifying project specific construction opportunities during later stages of design and minimal review of completed design documents. This effort often identifies major opportunities, but implementation is left for contractors, normally after bid and once costly manpower, material, and equipment are already on site. In most instances, significant interest is not provided until designs are 50% or more complete, where

potential benefits are limited and efforts to make changes are difficult and costly. Construction experts participating in planning and design can provide critical information on labor and material availability, appropriate construction methods and technologies, construction sequencing, new concepts, materials, and systems, and practical advice on field conditions (CII 1987). Constructability provides the logical integration of design and construction and has proven to provide "cost reductions of between 6 to 23 percent, benefit/cost ratios of up to 10 to 1, and significant schedule reductions" (CII 1993).

2.4 CONSTRUCTABILITY IN BUILDING PROJECTS

It is interesting to know what constructability is and how it complies with the principles of modern management philosophy, but what are the benefits to construction?, has it been proven effective?, and why focus on building projects? The remainder of this chapter provides the answers to these questions.

2.4.1 History of Constructability Use

Constructability began as one of the seven initial construction improvement opportunities researched by CII. Early research efforts found that significant cost and time savings could accrue from the careful interaction of design with construction and from improvements in techniques and management polices (O'Connor 1983). Further CII-related research states that constructability ideas are "an untapped resource waiting for the proper management approaches to discover and exploit" (Glanville 1985). As the concepts and ideas on the subject

were transferred into an implementation guide, CII began preaching the integration of design and construction as "the present key opportunity for greater effectiveness" on projects (CII 1986). In fact, constructability is responsible for CII's early creditability within the Construction Industry, and despite initial reluctance and controversy, even over its spelling, constructability has become a way of life in the industrial construction sector.

2.4.2 Lack of Full-scale Implementation

Over the last decade, CII member companies implementing the concepts and ideas of constructability on their projects have reported significant benefits. In fact, results presented at the 1995 CII Conference showed that fifty-one member companies reported constructability utilization on ninety percent of their projects (1,360 projects were in the data set), averaging total installed cost savings of five and one-half percent, ranging from three percent to as high as eight percent (Tucker 1995). The majority of this success, however, has only been seen on the larger industrial-based projects and to a large extent, these proven cost saving ideas have gone unused by the building sector. Documentation on TQM implementation efforts in other industries poses the likely reasons to be the building sector's false rational that the differences in building and industrial projects negate constructability's effectiveness, potential returns on the investment do not warrant additional up-front expenses, and complacency with their use of current practices.

Building projects are different than industrial projects in many aspects. Building projects use designers further separated from contractors while industrial projects often use the same company for design and construction or require a direct working relationship between the two. The separated relationship where designers work more with the owner and are rarely involved with the contractor minimizes the influence a contractor has on project success. Building projects most often use a general contractor who hires out the majority of work to subcontractors where industrial contractors often do all the work themselves through direct hire. In addition, building projects most often relying on fixed-price, design-bid-build contracts and industrial projects using more flexible cost-plus, engineer-procurement-construction (EPC) contracts. Although these differences exist and may require changes in the CII defined structure of a constructability program, they do not limit constructability's focus on the construction phase as the largest potential area for project savings or take away from the other benefits beyond hard-dollar costs.

2.5 BENEFITS OF CONSTRUCTABILITY USE

Why pursue constructability? … constructability can support all project objectives: reduced cost, shortened schedules, improved quality and safety, and enhanced management of risk (Young 1998). By decreasing scope and construction difficulty, improving methods of construction, increasing the use and effectiveness of improved technology, and incorporating the importance of local practices and limitations (CII 1986), constructability directly effects the bottom-

line cost of a project endeavor. Documented cost and schedule reductions of 4.3 to 7.5%, respectively, with 10:1 returns on investment (Young 1998) are a direct result of construction operations comprising the most expensive part of the project development process. When improvement efforts are aimed at the largest area of cost, the potential savings from improvements increases.

Looking at construction from the perspective of an owner or developer, construction costs average 50% of an overall investment (Peterson 1998). The average costs for real-estate projects are broken down as follows:

Land Costs	15%
Infrastructure	10%
Construction	50%
Soft Costs	15%
Profit	10%

Further breakdown of the costs of construction activities reveals that the actual construction of a facility averages 45% of the total installation costs of a project with only 8-15% for design (CII 1986). By using a constructability program, the emphasis on improvement focuses on the part of a project that ends up controlling the majority of the costs. Therefore, owners' of building projects, as did the leading industrial companies, need to begin improvement efforts with constructability to address the project area with the most potential for savings and influence on project success.

Most often the hard-dollar cost savings are the most convincing to initiate change, but the benefits of a properly implemented constructability program go

beyond these savings. Significant benefits come from the soft-issues, the ones that are difficult to quantify or even put dollar values against. The most important aspect of constructability is its focus on project success through the early integration of project participants. Integration is accomplished through the development of a common goal focused on completion of the project and ensuring customer satisfaction.

"Constructability functions as a powerful planning vehicle in drawing all project team members together in a structured approach based on customer requirements and a "right-the-first-time" execution approach" (Geile 1996). It compels all project team members to adopt a project viewpoint. The influence of construction's involvement in early project planning and design not only reduces cost and schedule and improves quality and safety, but it aligns team efforts with the long-term business objectives of the owner. Therefore, project participants, whether in-house or contracted, see their place on the owner's bottom line and understand their influence on project success. "It is critical to have a vision driving the ... project as defined by the customer" (Geile 1996) and constructability becomes the vehicle to accomplish this task.

Additional soft-issue benefits from constructability use are closely tied to creating a common goal between project participants. Constructability also improves project performance by enhancing intangibles like teamwork, planning, and productivity. Under the structure of a constructability program, project team members begin to understand others viewpoints and establish lines of communication that foster problem solving and camaraderie. Emphasizing

constructions early involvement in the process, constructability forces pre-planning efforts to discover problems early, before they can affect project performance. The improved teamwork and planning lay the groundwork for higher levels of productivity during field operations.

2.6 SUMMARY

In general, the construction industry can benefit from the TQM principles discovered in the manufacturing industry. Although differences are apparent between these industries, the management philosophy of TQM is applicable to both. Continual improvement through teamwork is the key to success on any project and by structuring the work environment to emphasize quality from the onset, the construction industry can reap the benefits of faster, cheaper, better quality projects. By developing a structured constructability program an integrated team approach can be re-built. Under the umbrella of constructability, engineering and construction can implement continuous improvement on building projects, focusing improvement efforts where the greatest potential savings exist and using a system that fosters the additional benefits of team building, early planning, and increased productivity.

Chapter 3: Methodology

The method of research instituted in this thesis is a combination of existing data analysis and an on-site field study. As stated in the purpose, this thesis is an attempt to support the use of Constructability as a necessary avenue for improvement in building projects. Shown in Figure 3.1, a classical literature review process was used, but a concurrent data gathering effort supplemented project data found in the Construction Industry Institute's (CII) Benchmarking and Metrics (BM&M) Database with specific constructability observations realized on a typical building project.

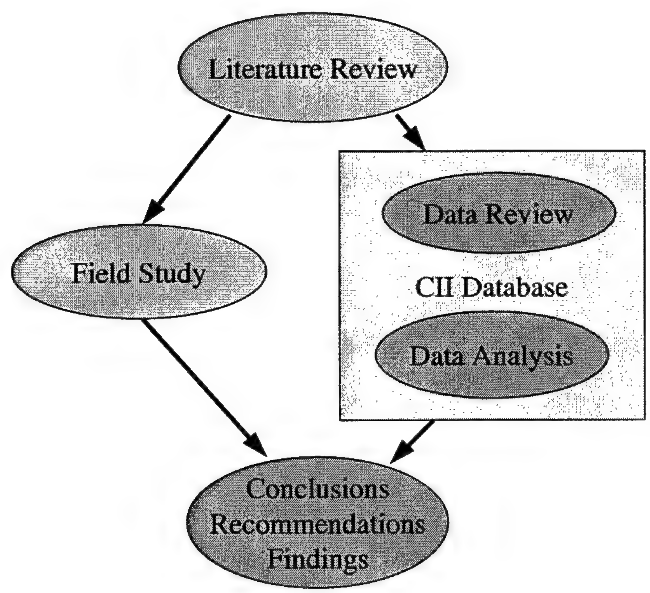


Figure 3.1 – Research Methodology

3.1 LITERATURE REVIEW

A comprehensive literature review has been performed into relevant material on Total Quality Management (TQM) and Constructability. There is a plethora of books and articles on TQM. Providing a background on TQM was important to highlight its attributes and show how the success elements discovered by manufacturing can be used on building projects in the form of a Constructability Program. The constructability research was mainly found in CII documentation, articles based primarily on CII work, or other theses and dissertations related to CII. The CII influence provided information primarily geared for heavy industrial projects with larger management organizations, but included implementation actions, supporting data, and individual success stories.

3.2 PROJECT DATA

The project data contained in this thesis was obtained from the CII BM&M Database. The initial purpose of this section is recognition of CII for its role in this thesis by describing the organization and its BM&M Program. Secondly, this section explains why and how the BM&M Database was utilized and then describes the data analysis process.

3.2.1 Construction Industry Institute

CII is a national research organization consisting of more than 80 of the Construction Industry's leading owners, contractors, and architect/engineers. The concept for this hands-on, member-involved research organization was developed

by the University of Texas, Construction Engineering and Project Management Program. Founded in 1983, CII performs some of the following activities: analysis, depository, information, and retrieval of data, research, standards, interface relations, conferences, publications, continuing and informal education (Porter 1997). Currently the CII mission is:

> .... to improve the safety, quality, schedule, and cost effectiveness of the capital investment process through research and implementation support for the purpose of providing a competitive advantage to its members in the global marketplace.

Since 1983, CII member companies working with over 30 universities have produced over 350 research publications, implementation resources, videotapes, and software products dedicated to improving the industry (CII 1998). CII is lead by a director, but research efforts are steered by a Board of Advisors consisting of representatives from member companies. CII is administratively based at The University of Texas at Austin.

An extensive background of CII, its research process, and the BM&M Program can be found in Contractor Influence on Project Performance, a thesis by Brandon Porter, University of Texas at Austin, 1997. In addition, CII is located at 3208 Red River Street, Suite 300, Austin, Texas 78705 or on the web at http://construction-institute.org.

3.2.2 Benchmarking and Metrics Program

The BM&M Program was founded by CII in 1993 with "the mission of developing policy and recommending a strategic approach to the collection,

analysis, and dissemination of industry data" (Porter 1997). The program has adopted the following definitions for metric and benchmarking:

> Metric – A quantifiable, simple, and understandable measure which can be used to compare and improve performance.
>
> Benchmarking – A systematic process of measuring one's performance against results from recognized leaders for the purpose of determining best practices that lead to superior performance when adopted and utilized.

The BM&M Committee is an on-going effort by one of the largest chartered groups in CII to meet three major objects:

1. Provide the industry with "norms."
2. Measure the use of "Best Practices" and quantify the value of implementing CII recommended practices.
3. To help educate the industry in benchmarking practices and interpretation of data for improvement within their respective companies.

The Committee decided the best way to accomplish this task was to develop a database, collecting project data from member companies. The data collection was accomplished through the use of a questionnaire designed to effectively gather project data quickly and efficiently, while focusing on CII recommended practices. The intent of these efforts is not to provide in-depth analysis of individual projects or companies, but to provide the tools necessary for companies to perform in-house analysis of project performance and identify their own improvement opportunities. The tools provided by the Committee include a set of well-defined performance metrics, a report of industry norms for comparison, and a report of general analysis which identifies practices that correlate to successful project performance (BMM 1998).

3.2.3 Using the BM&M Database

The BM&M Committee developed a questionnaire and orchestrated two separate data gathering efforts collecting project-related information on almost 400 projects. The large size of the database and numerous topics explored by the questionnaire provide many different research possibilities. The author's research focus was developed through exposure to the database contents, specific classroom study on "Constructability", and prior work experience in the Construction Industry.

Although including many building projects, the majority of the projects, almost 60%, represented in the BM&M Database are heavy industrial. Past CII research has shown constructability efforts provide significant cost and schedule savings during project case study research and the BM&M Database, as a whole, shows positive trends in project performance as constructability use increases. However, what about building projects? Does increased constructability use correlated to positive trends in project performance for them? In addition, do other CII-endorsed quality-based best practices such as pre-project planning and team building relate to constructability use?

3.2.4 Data Gathering

With the correct types of data already complied by CII, the data gathering process for this thesis included studying the database questionnaire and related index calculations and ensuring enough building projects were available for

analysis. Investigation of the first two versions of the BM&M data revealed the database contained a constructability use index and three key project performance measurements, cost growth, schedule growth, and safety. In addition, the database contained constructability-related best practice indices for pre-project planning and team building use. Working with CII staff members, the topic-related data was extracted from the database discovering 58 building projects with 69% (40 projects) indicating some degree of constructability use. A detailed presentation of this data as well as background on the entire BM&M Database is included in Chapter 4. The BM&M Owner and Contractor, Version 2 Questionnaires used to collect the data are included as Appendix A and B respectively. Calculations for the selected performance metrics and practice use indices are discussed in Chapter 4.

3.2.5 Data Analysis

Armed with data from 58 building projects, the next step was to analyze the data to reveal possible correlation between constructability use and project performance measures (cost growth, schedule growth, and safety). Microsoft's Excel Data Analysis Pak was used to perform linear regression analyses between constructability use and project performance measures. Project data records were removed from analysis efforts if data was not provided in a field. For example, if a project's schedule growth was not available, meaning the questionnaire did not provide the appropriate data for calculation, that project's record would be excluded from the analysis of constructability use versus schedule growth.

The second series of analyses were conducted to reveal a correlation between constructability use and other quality-based best practice uses. A visual review of the data showed some similarity in data records between extent of constructability use and extent of pre-project planning or team building use. Again, Microsoft's Excel Data Analysis Pak was used to perform linear regression analyses to determine the degree of correlation. Additional analyses were performed to investigate further correlation between owner projects and contractor projects use of constructability versus pre-project planning use and team building use.

3.3 FIELD STUDY

A field observation study was performed during a three-month internship with a respected South-Texas General Contractor building a $18.5 million grassroots community college campus in San Antonio, Texas. Project highlights include:

- A standard lump-sum, design-bid-build contract strategy
- A government entity as the owner
- The general contractor subcontracted the majority of the work
- The project included both union and open shop contractors
- The scope of work included:
    - Sitework – selective site clearing, permanent storm water runoff control, pedestrian bridges, parking, roads, and underground utilities

- Central Plant – building and equipment for chilled water system, commercial power tie-in, and campus maintenance functions
- Academic Building – 2-story building with combination of classroom, office, and laboratory space
- College Commons – 2-story building with cafeteria, conference space, and additional office areas.
- Learning Center – 2-story building with library and additional office space

In the position of a field engineer and quality control assistant, the author became familiar with drawings, specifications, and project administrative processes while actively working requests for information, change orders, material procurement, submittals, etc. In addition, a variety of weekly project meetings including owner-driven, contractor staff, foreman, and safety meetings were attended gaining insight to the effectiveness of project coordination and communication. From these activities and multiple informal discussions with field staff, foreman, and craftsmen, a notebook of constructability lessons learned and improvement opportunities was kept. The purpose of gathering this information was to verify constructability-based improvement opportunities existed in building projects and actual field problems that had the potential of being eliminated or at least minimized by using constructability as a front end planning tool. The constructability lessons learned and improvement observations discovered during the field study are included as Chapter 6.

Chapter 4: Data Presentation

The purpose of this chapter is to present the characteristics of entire Benchmarking and Metrics (BM&M) Database, specifically discuss the 58 building projects, and explain the Construction Industry Institute's (CII) best practice indices and performance measures used for analysis in this thesis.

4.1 BM&M DATABASE

At the time of writing this thesis, the BM&M Database contained 393 projects from 30 owners and 29 contractors representing over $20.6 billion in construction. The following paragraphs and accompanying figures attempt to give a perspective of where the data came from and how results from the analysis might be best applied. The information presented in this section is a reproduction of that found in the Benchmarking and Metrics Data Report for 1997 printed by CII.

The 393 projects in the database include 209 submitted by contractors and 184 submitted by owners. Figure 4.1 shows this breakdown of the database by respondent type and illustrates the equal representation of owner and contractor projects. With an average of seven projects submitted per participating company, the number of owner and contractor companies represented is also even, 30 and 29 respectively.

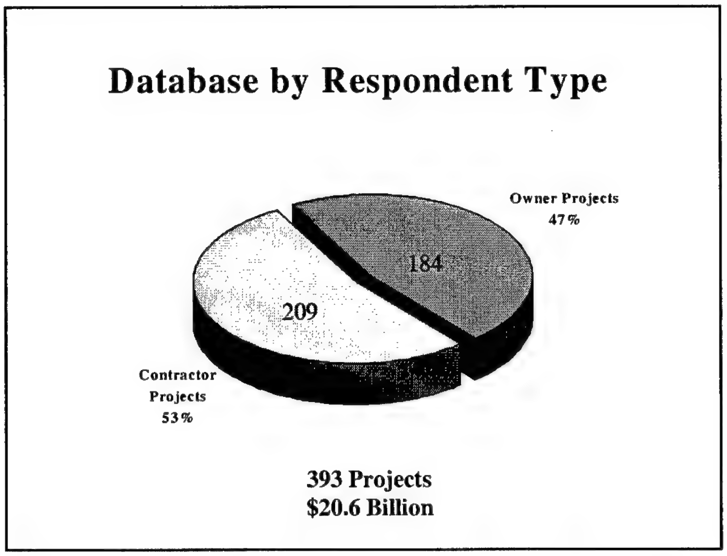


Figure 4.1 – Database by Respondent Type

The project data provided by the contractors includes information pertaining only to their involvement in the project. Therefore, it is important to understand the types of contractor functions represented in the database. Figure 4.2 presents the breakdown of functions provided by contractors in the database. Over half the contractors in the database provided design/build services on their projects.

The BM&M Database categorizes the construction industry into four main construction groups. These groups are buildings, heavy industrial, infrastructure, and light industrial. Figure 4.3 illustrates the composition of the database by industry group. It can be seen that almost 60% of the database projects are heavy industrial, however, 58 projects are from the building sector.

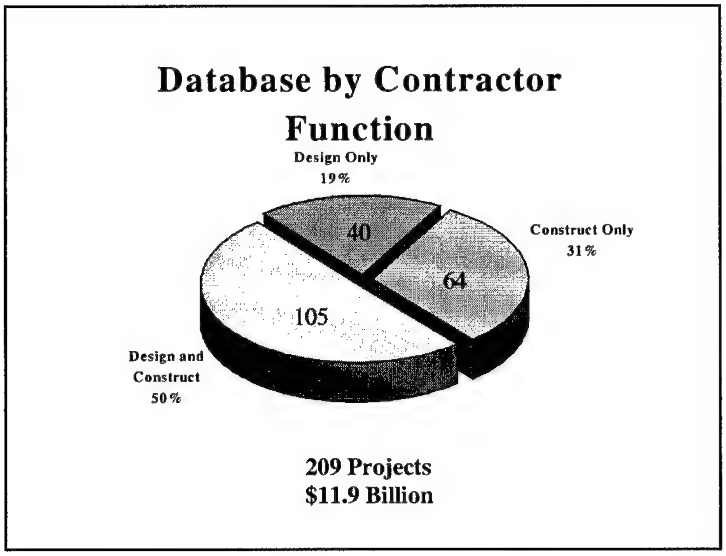


Figure 4.2 – Database by Contractor Function

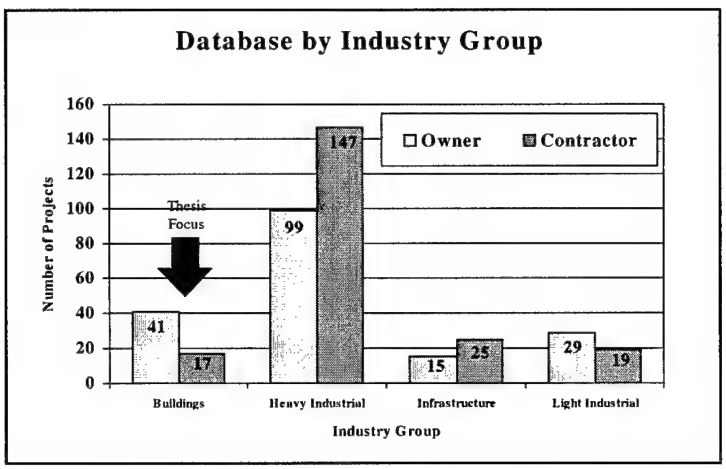


Figure 4.3 – Database by Industry Group

The database can be further broken down and described by project type. Figure 4.4 shows the four types of projects most represented in the database.

These are chemical manufacturing with 97, oil refineries with 58, pulp and paper with 34, and electrical generation with 24.

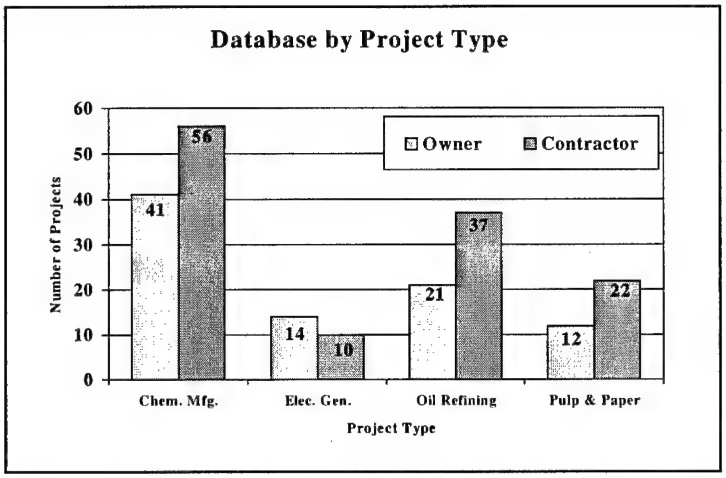


Figure 4.4 – Database by Project Type (Top 4)

Figure 4.5 illustrates the cost breakdown of projects in the database. Approximately one-third are less than \$15 million, one-third are between \$15 million and \$50 million, and the remaining third are in excess of \$50 million. The range of individual project costs is \$5 million to more than \$500 million.

Projects in the database can be further broken down by the "nature" of the project, illustrated in Figure 4.6. These include:

Grass roots - new facilities from the foundation up,
Additions - new facility component tying into existing facilities, or
Modernizations - substantial upgrades to equipment or structure of an existing facility.

The projects in the database are evenly spread between the three project natures.

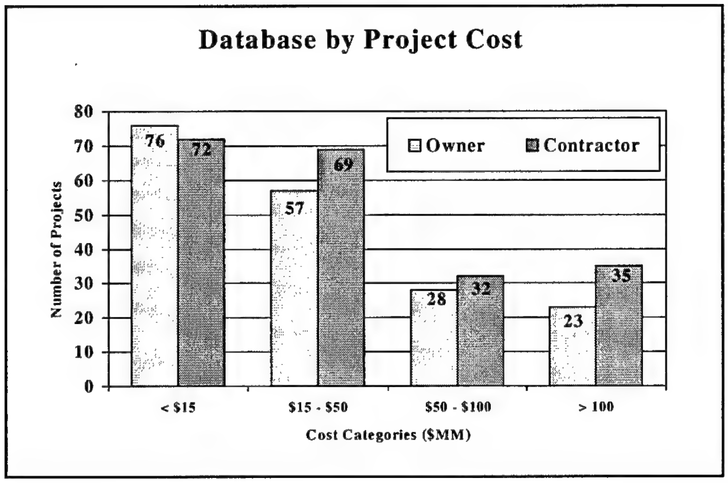


Figure 4.5 – Database by Project Cost

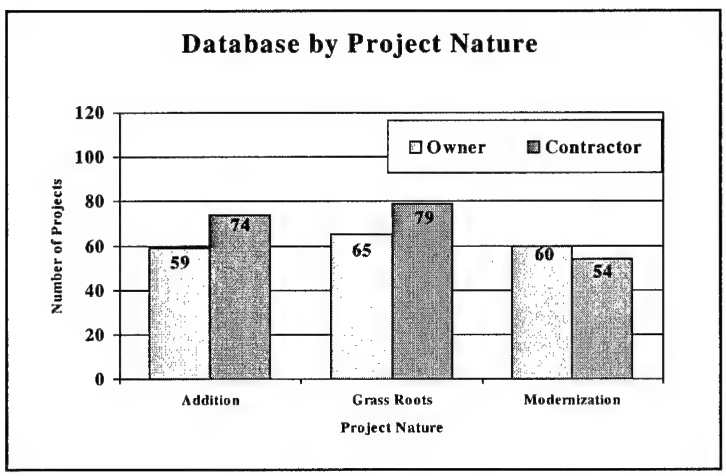


Figure 4.6 – Database by Project Nature

4.2 BUILDING PROJECT DATA

Data from the 58 building projects in the BM&M Database were analyzed in this thesis. The following figures and tables break down these projects to provide a understanding of their background, relationships, and potential application medium.

The building projects are not as evenly divided among owners and contractors, as the division found in the database at large. There were 41 owner projects and 17 contractor projects submitted as building sector projects. Figure 4.7 illustrates the breakdown showing owner building projects making a little over 70% of the projects. However, Figure 4.8 shows that the private and public break down is even.

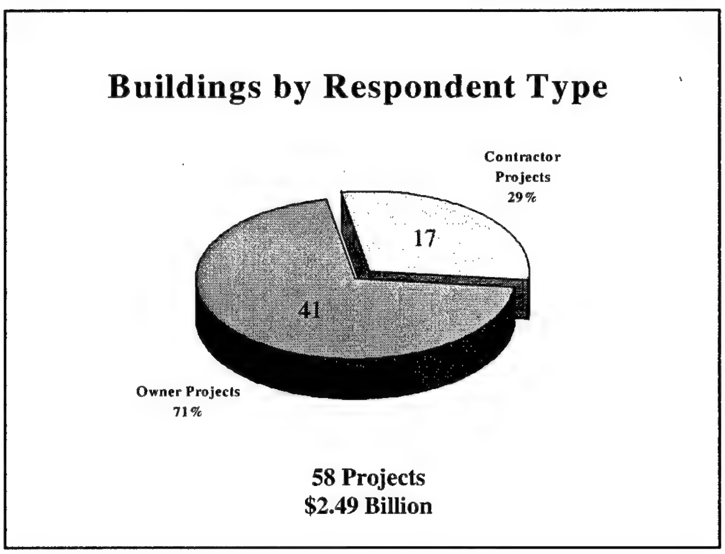


Figure 4.7 – Buildings by Respondent Type

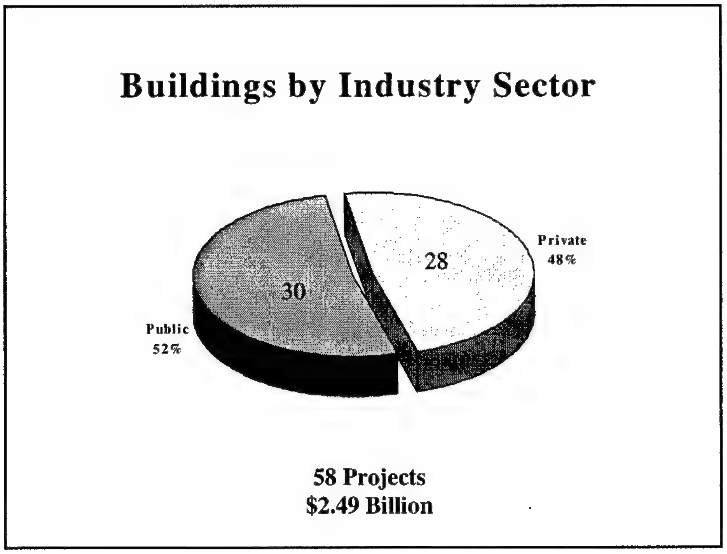


Figure 4.8 – Building Projects by Industry Sector

The influence of constructability on a project increases with earlier implementation, as was illustrated by the Cost Influence Curve in Figure 2.1. Therefore, it is important to understand the extent to which contractor influence was allowed on the building projects and under what type of contractual arrangements they functioned. Figure 4.9 shows the contractor influence through function on the project. Half the contractors provided construction service only and the other half design and construction. One contractor in the data pool was only a designer. Owner projects showed that only 3 of 41 projects used design-build contractors. Figure 4.10 shows design contract types employed on the projects and Figure 4.11 shows the construction contract types.

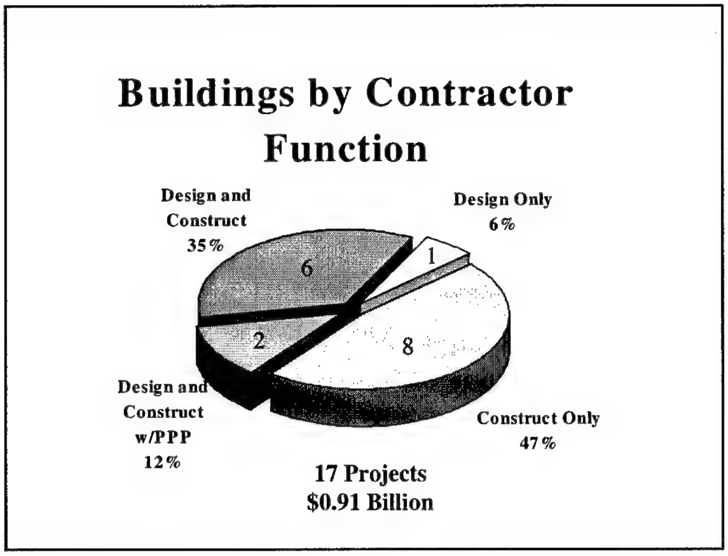


Figure 4.9 – Building Projects by Contractor Function

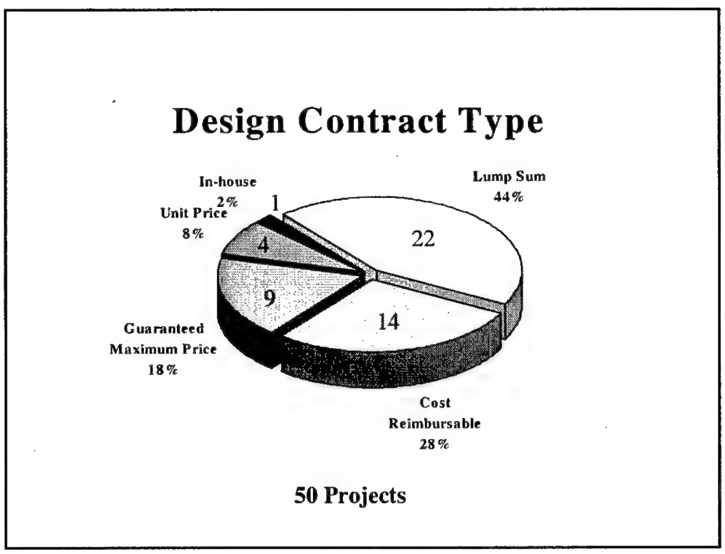


Figure 4.10 – Building Projects Design Contract Type

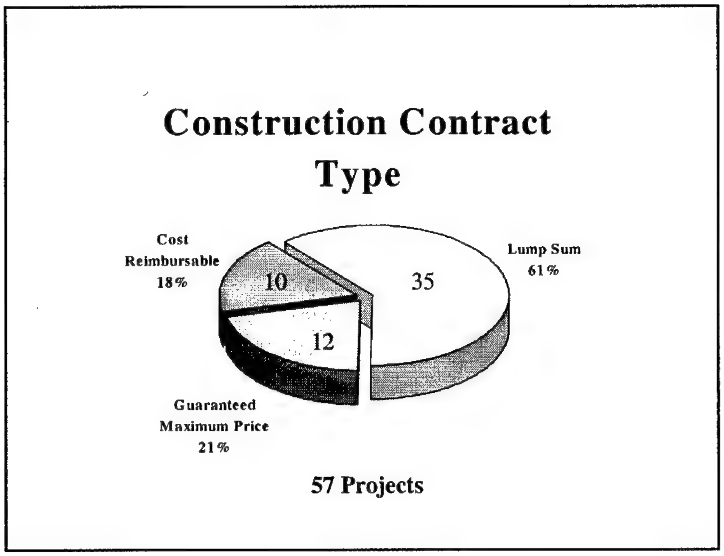


Figure 4.11 – Building Projects Construction Contract Type

Only 50 projects are presented in Figure 4.10 because eight of the contractors were involved only in construction and did not report design contract type. It can also be seen that a majority of the building projects, over 50%, used the traditional lump sum bid contract. The other half of the projects used more modern contract vehicles like cost reimbursable and guaranteed maximum price.

For application reasons, it is also important to note the type of projects in the data set. Table 4.1 lists the project types represented along with number observed and percent of the data set. Low-rise office facilities make up the majority of the projects with 18, followed by laboratories with 11. These two building types represent 50% of the projects in the data set.

Project Type	No.	%
Lowrise Office	18	31.0%
Laboratory	11	19.0%
Maintenance Facilities	5	8.6%
School	5	8.6%
Warehouse	4	6.9%
Hospital	4	6.9%
Dormatory/Hotel	3	5.2%
Retail Building	3	5.2%
Highrise Office	2	3.4%
Restaurant/Nightclub	1	1.7%
Parking Garage	1	1.7%
Housing	1	1.7%

Table 4.1 – Building Projects by Project Type

Eighty percent of the building projects are less than $50 million dollars, with approximately 40 percent less than $15 million, and 40 percent of the projects between $15 million and $50 million. Only 10 building projects are over $50 million. Figure 4.12 illustrates the cost category breakdown for the 58 projects.

The nature of the building projects is illustrated in Figure 4.13. It shows that over 70% of the projects are grass roots, meaning 43 of the projects were constructed from the foundation up. The remaining projects are evenly distributed between additions and modernization projects.

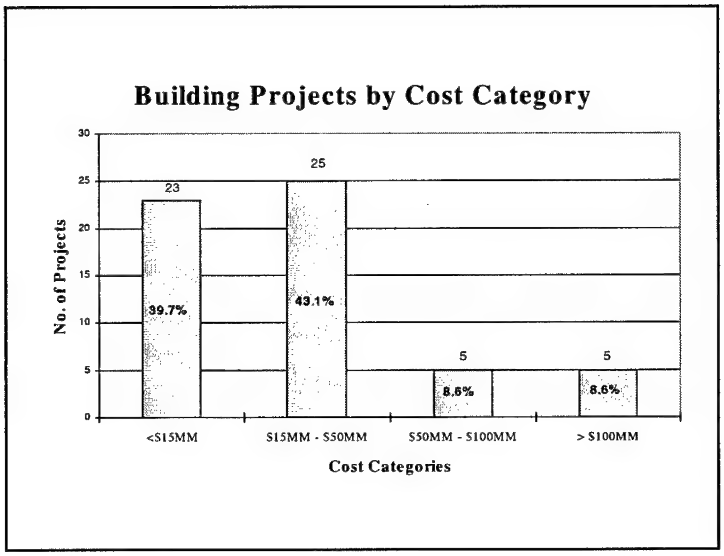


Figure 4.12 – Building Projects by Cost Category

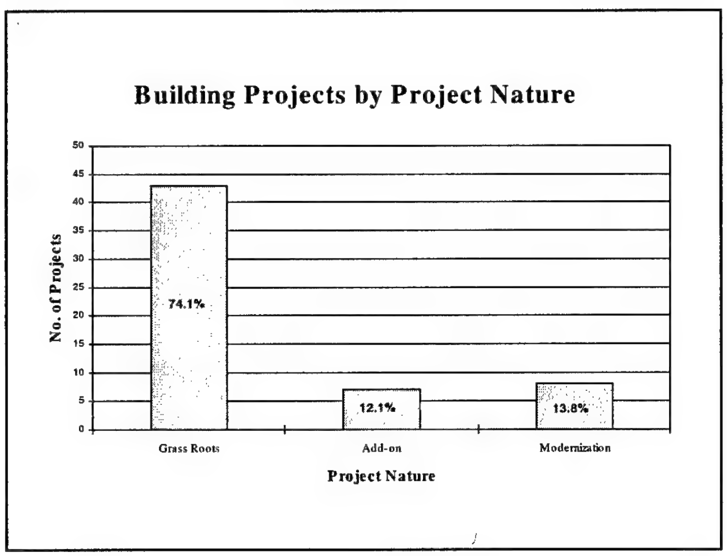


Figure 4.13 – Building Projects by Project Nature

4.3 BEST PRACTICES INDICES

As discussed in Chapter 3, the BM&M data collection effort focused on CII recommended practices. These "Best Practices", as termed by CII, are those project improvement activities which research has proven to provide financially quantifiable benefits (Tucker 95). The Constructability, Pre-project Planning, and Team Building best practice use indices were utilized in this thesis. The purpose of this section is to explain how these practice use indices were calculated from responses to the BM&M Questionnaires and review the index values obtained in the building projects data set. The owner and contractor versions of the BM&M Questionnaire, Version 2 are included as Appendix A and B, respectively.

4.3.1 Indices Calculations

Appendix C is an example of how the Constructability, Pre-project Planning, and Team Building practice indices are calculated. The example as well as the explanation is summarized from Benchmarking and Metrics Data Report for 1997. A summated rating scale is used to develop an index score between zero and ten. If all practice elements were used to the highest degree, the practice index is ten, if none were used, the practice index is zero. For Constructability and Team Building, questions pertaining to elements of each best practice are given equal value. Values corresponding to responses for each question are summed and then divided by the maximum possible score to calculate the zero-to-ten practice use index. The Pre-project Planning use index is calculated using a weighting system developed by the CII Pre-Project Planning

Research Team. "Not applicable" responses are given maximum element value to reduce overall effect on the index score.

4.3.2 Best Practice Use in the Building Projects

The average index scores, range values, and number of projects with valid data are shown in Table 4.2. The data set shows a low average use index for constructability and team building, 3.70 and 4.84 respectively. The range of responses for both indices is 0 to 10. The pre-project planning index average is much higher at 6.85 with all projects showing some use of the practice. The range was 2.25 to 10.

Best Practice Index	Average Score	High Value	Low Value	No. of Projects
Constructability Index	3.70	10	0	56
Pre-project Planning Index	6.85	10	2.25	53
Team Building Index	4.84	10	0	56

Table 4.2 – Building Projects Best Practice Index Averages

For this thesis in particular, it is relevant to explore the percent of projects using the best practices of constructability, pre-project planning, and team building. It is important to have projects both using and not using the practices to get a good understanding of the extent to which project measures or other practice uses are improved with increasing constructability use. For these 58 building projects, 70% indicated some use of constructability. Additionally, the projects showed high usage of both pre-project planning and team building. Figure 4.14

shows the best practice utilization for the data set. "Percent Use" as shown on the Y-axis of Figure 4.14 is the percent of projects acknowledging some use of the best practice, meaning index scores of greater than zero. One owner project did not provide sufficient information to have best practice indices calculated and, therefore, only 57 projects are represented.

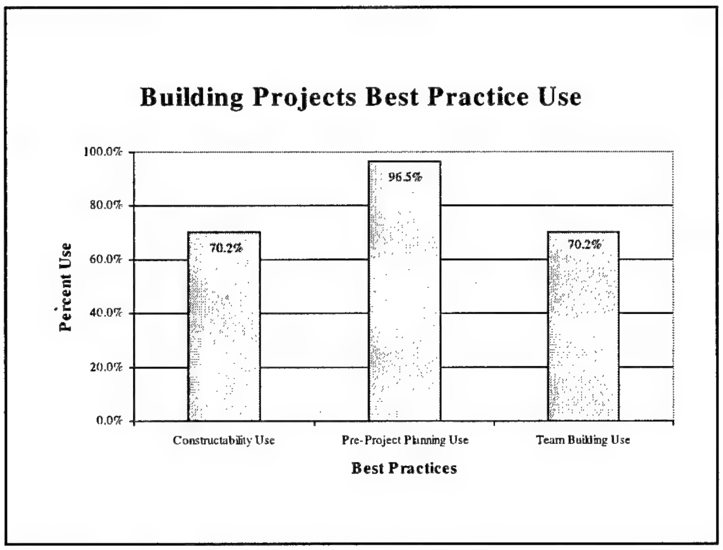


Figure 4.14 – Building Projects Best Practice Use

4.4 PERFORMANCE MEASURES

Another aspect of the BM&M Database pertinent to this thesis is the definition and calculation of project performance measures. To show financial benefits for constructability use, it is important to analyze the relationship between constructability and performance measures such as cost growth, schedule growth, and safety. The purpose of this section is to present the BM&M methods for calculating cost, schedule growth, and two safety measurements, Recordable

Incident Rate (RIR) and Lost Workday Case Incident Rate (LWCIR). In addition, the section will review the values for performance measures contained in the building project data set.

4.4.1 Performance Measure Calculations

Cost growth measures the ratio of change in project costs to the initial project estimates. Positive cost growth means that the actual cost of a project is greater than the initial amount estimated. In turn, negative cost growth means final project costs were less than originally estimated. The formula and definitions used in the BM&M Database for cost growth are shown in Table 4.3.

Metric:	**Formula:**
Project Cost Growth	$\dfrac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
Definition of Terms <u>Actual Total Project Cost</u>: Industrial Sector Owners – Total Installed Cost at Turnover, excluding land costs. Building Sector Owners – Total Cost of design and construction to prepare the facility for occupancy. Contractors – Total cost of the final scope of work. <u>Initial Predicted Project Cost</u>: Owners – Budget at the start of detail design. Contractors – Cost estimate used as the basis of contract award.	

Table 4.3 – Cost Growth Calculation

Schedule growth measures the ratio of change in project duration to the initial estimate for project duration. Positive schedule growth means project completion took longer than estimated. Therefore, negative schedule growth means the project was completed more quickly than estimated. Table 4.4 presents the BM&M Database formula for schedule growth, along with the definitions for project duration.

Metric:	**Formula:**
Project Schedule Growth	$\dfrac{\text{Act. Total Proj. Duration} - \text{Init. Predicted Proj. Duration}}{\text{Init. Predicted Proj. Duration}}$

Definition of Terms

Actual Total Project Duration:

Owners – Duration from beginning of detail design to turnover to user.
Contractors - Total duration for the final scope of work from mobilization to completion.

Initial Predicted Project Duration:

Owners – Duration prediction upon which the authorization to proceed with detail design is based.
Contractors - The contractor's duration estimate at the time of contract award.

Table 4.4 – Schedule Growth Calculation

The BM&M Database utilizes the Occupational Safety and Health Administration (OSHA) definitions and formulas for RIR and LWCIR. The RIR is the number of recordable incidents occurring on a project multiplied by 200,000 hours and divided by the number of hours worked on the project. "The 200,000 hours in the formula represents the equivalent of 100 employees working 40 hours per week, 50 weeks per year, and is the standard base for incidence

rates" (The Business Roundtable 1982). The LWCIR is the number of lost workday cases on a project multiplied by 200,000 hours and then divided by the number of hours worked on the project. Table 4.5 shows the formulas and definitions used to calculate RIR and LWCIR.

Metric:	Formula:
Recordable Incident Rate (RIR)	$\dfrac{\text{Total Number of Recordable Cases x 200,000}}{\text{Total Craft Workhours}}$
Metric:	**Formula:**
Lost Workday Case Incident Rate (LWCIR)	$\dfrac{\text{Total Number of Lost Workday Cases x 200,000}}{\text{Total Craft Workhours}}$

Definition of Terms

- Recordable Cases: All work-related deaths and illnesses, and those work-related injuries which result in loss of consciousness, restriction of work or motion, transfer to another job, or require medical treatment beyond first aid.
- Lost Workday Cases: Cases which involve days away from work or days of restricted work activity, or both.

Table 4.5 – RIR and LWCIR Calculations

4.4.2 Performance Measures in the Building Projects

Table 4.6 shows each performance measure's average value, range of values, and number of project records with valid data. The schedule and cost growth averages for the data set are 11.2% and 2.7% respectively. Both of these measures displayed relatively large ranges with schedule growth ranging from –119.2% to 212.6% and cost growth ranging from –32.5% to 65.5%. The RIR

average is 5.89 with a range of 0 to 50. The LWCIR average is 1.52 with a range of 0 to 12.9.

Performance Measure	Average	High Value	Low Value	No. of Projects
Schedule Growth	11.2%	212.6%	-119.2%	54
Cost Growth	2.7%	65.5%	-32.5%	57
RIR	5.89	50.0	0	38
LWCIR	1.52	12.9	0	37

Table 4.6 – Building Project Performance Measure Averages

4.5 SUMMARY

The building project data is well representative of the BM&M Database as a whole. Specifically, the building data set more heavily represents owner projects with contractor functions of design/build and construction only, working under lump-sum contracts. In addition, the projects are grassroots in nature and under $50 million in cost, but represent a wide-range of common building types. The project practice indices for Constructability, Pre-project Planning, and Team Building provide a sufficient range of data to conduct useful analysis. The project performance measures of cost growth, schedule growth, RIR, and LWCIR indicate that a healthy range of successful and not-so-successful projects will be represented during analysis.

Chapter 5: Data Analysis and Results

Chapter 3 discusses the dual-track data-gathering course employed during development of this thesis. This chapter explains the process employed and results discovered during analysis of the 58 building projects found in the Construction Industry Institute's (CII) Benchmarking and Metrics (BM&M) Database. This database provided a rich source of constructability-relevant data on building projects including project performance measures and quality improvement best practices. The project performance measures included cost growth, schedule growth, and safety while the best practices included constructability, pre-project planning, and team building. From this data set, two series of analyses were performed to prove constructability's role in building project success. The first series of analyses searched for a positive relationship between constructability use and each of the project performance measures. The second series of analyses searched for a quality improvement theme by relating constructability to pre-project planning and teambuilding. Further information on the 58 building projects, the CII BM&M Database, the best practice indices, and the performance measures is contained in Chapter 4.

5.1 Analysis Process

Linear regression was utilized for data analysis and Microsoft Excel's Data Analysis Pak was used for all calculations. Regression analysis evaluates:

> ...the dependence of one variable, the dependent variable, on one or more other variables, the explanatory variables, with a view to estimating and/or predicting the mean or average value of the former in terms of the known or fixed values of the latter (Gujarati 1995).

In terms of this thesis, linear regression evaluates the dependence of project performance measures on the extent of constructability use with the intent to estimate future project performances depending on extent of constructability implemented.

Before analyses began, the entire data set was reviewed for completeness of data. The 58 building projects in the BM&M Database were reduced to 56 projects for analysis. The first project was eliminated because sufficient information was not provided on the project questionnaire to CII for calculation of project measures or practice use. The second project was eliminated because it did not contain a calculation for the constructability index.

For each regression analysis, the 56 building projects were reviewed for completeness of data regarding the ensuing analysis. Project records not containing appropriate data for the particular regression analysis were removed from the data set. For example, during analysis of schedule growth versus constructability, four project records were eliminated because three did not have calculated schedule growths and one was an extreme outlier.

After the data set was reviewed, the data points were fed into Microsoft Excel's Data Analysis Pak and regression analysis performed. Output from the analysis was directed into chart format to display all data points and a corresponding regression line on a scatter-plot diagram. The constructability

index is displayed on the X-axis as the explanatory variable and the various other measures or practices are displayed on the Y-axis as dependant variables.

On each chart, project data points are distinguished according to cost categories to further recognize potential trends based on project cost. Although data presentation in Chapter 4 shows four separate cost categories in the data set, the top three categories were combined into one during analysis to protect confidentiality in accordance with BM&M Database policy. This policy being, "Aggregate results will only be reported if the analysis consists of at least 10 projects reported by at least three separate companies" (CII 1998).

5.2 RESULTS

After analysis was performed, results based on statistical relationships and personal interpretation were developed. These results along with the observations presented in Chapter 6 are the basis of this thesis. They will support or oppose the primary purpose of this thesis, which is to establish constructability as a viable quality improvement tool for building projects.

5.2.1 Constructability and Project Performance

The first series of regression analysis attempted to relate increased constructability use to improvement in project performance. A positive relationship between constructability use and project performance measures provides evidence of hard dollar savings associated with constructability implementation and the potential to predict performance outcomes from constructability use.

5.2.1.1 Schedule Growth versus Constructability Index

The first analysis in this series looked at the relationship between schedule growth and constructability use. Figure 5.1 is the scatter plot chart showing all data points and the regression line. Only 52 project records where used on this analysis, four were removed for missing data and one project was considered an outlier. The outlier showed a 212% schedule growth, which under normal industry standards is beyond excessive and most likely can be attributed to issues outside the control of a constructability program.

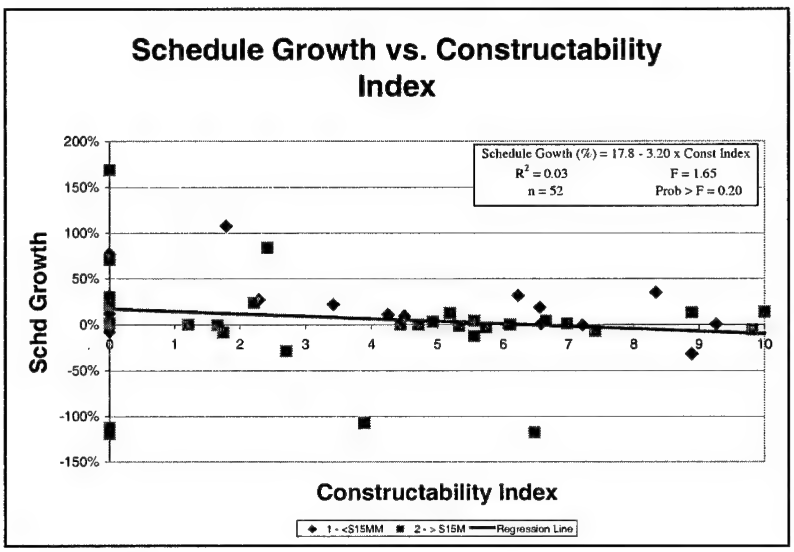


Figure 5.1 – Schedule Growth versus Constructability Index

Statistically the relationships in this data set are not significant; however, it is important to note the reduced range in schedule growth with increasing values of constructability index. This trend is interpreted to mean increasing use of constructability provides better control over project schedule growth. It is also

difficult to dismiss the obvious downward trend in schedule growth with increasing constructability use. The regression line of this data shows a potential decrease of 26% (17% to -9%) in schedule growth from zero constructability use to a maximum constructability use.

5.2.1.2 Cost Growth versus Constructability Index

The second analysis in this series looked at the relationship between cost growth and constructability use. Figure 5.2 is the scatter-plot diagram showing all data points and the regression line. All 56 projects contained the required data and are included in the analysis.

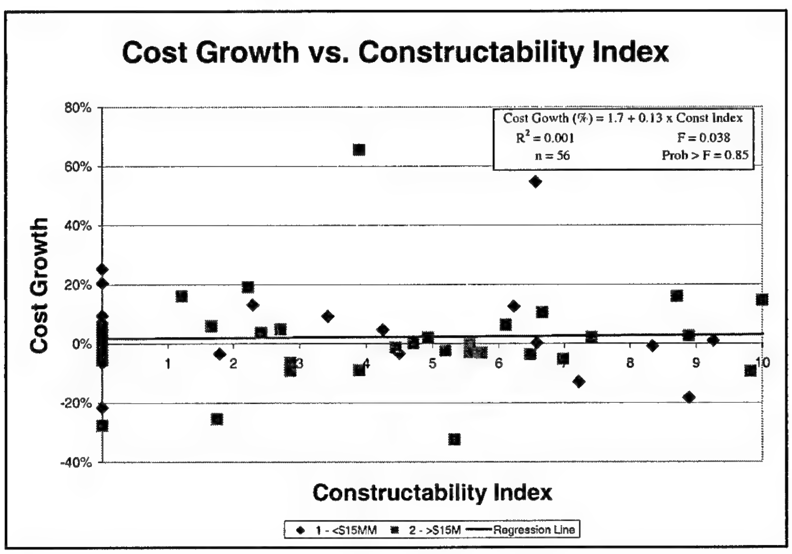


Figure 5.2 – Cost Growth versus Constructability Index

There are no significant statistical or interpreted results from this analysis. The breakdown of projects by costs also provides no visible trends.

5.2.1.3 Recordable Incident Rate versus Constructability Index

The third analysis in the series looked at the relationship between the Recordable Incident Rate (RIR) and constructability use. Figure 5.3 is the scatter-plot diagram showing all data points and the regression line. Only 38 project records out of 56 were used because 18 projects did not provide the appropriate data for the calculation.

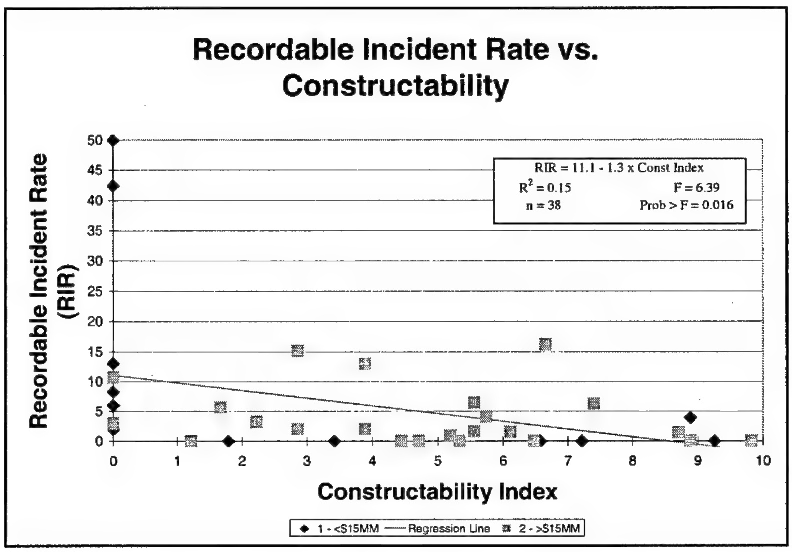


Figure 5.3 – Recordable Incident Rate versus Constructability Index

Statistically this analysis shows a significant correlation between constructability use and RIR. The relationship between RIR and constructability use has one of the strongest correlation coefficient and minimum variance ratio found in this research. The equation of the regression line indicates that for every 1-point improvement in constructability use there is a corresponding decrease of 1.3 in the RIR. This positive performance trend; a decrease in RIR for increasing constructability use, is interpreted to mean that for this data set constructability

has an affect on safety performance. The breakdown of projects by cost category provides no additional insight into the relationship.

5.2.1.4 Lost Workday Case Incident Rate versus Constructability Index

The final analysis in the series looked at the relationship between Lost Workday Case Incident Rate (LWCIR) and constructability use. Figure 5.4 is the scatter-plot diagram showing all data points and the regression line. Only 37 project records out of 56 were used because 19 projects did not provide the appropriate data for the calculation.

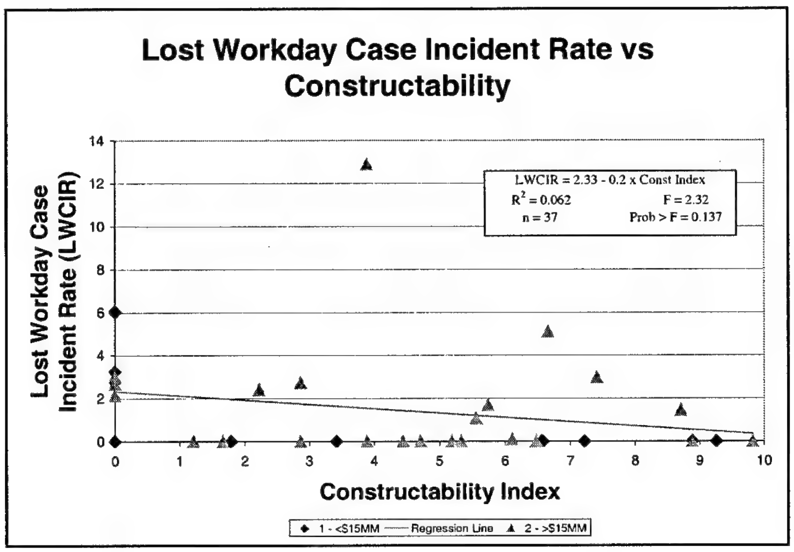


Figure 5.4 – Lost Workday Case Incident Rate versus. Constructability Index

Statistically the relationships in this data set are not significant; however, it is important to note the positive performance trend in the data; as constructability use increases the Lost Workday Case Incident Rate decreases.

This trend is interpreted to mean increasing use of constructability provides better control over project safety performance.

5.2.2 Constructability and Other Quality Practices

The second series of regression analysis attempted to discover relationships between constructability use and two other quality practices, pre-project planning and team building. A positive relationship between constructability use and other quality practices would provide evidence of a shared quality theme and support the premise that constructability is a catalyst for continuous project improvement.

5.2.2.1 Pre-project Planning versus Constructability Index

The first analysis in this series looked at pre-project planning use versus constructability use. Figure 5.5 is the scatter-plot diagram showing all data points and the regression line. Only 53 project records out of 56 were used in the analysis, three were removed for not having calculated pre-project planning indices.

Statistically this analysis shows a significant correlation between constructability use and pre-project planning use. The equation of the regression line indicates that for every 1-point improvement in constructability use there is a corresponding increase of 0.2 in the pre-project planning index. This positive relationship; an increase in one showed an increase in the other, is interpreted to mean that for this data set constructability has an affect on pre-project planning

efforts. The breakdown of projects by cost category provides no additional insight into the relationship.

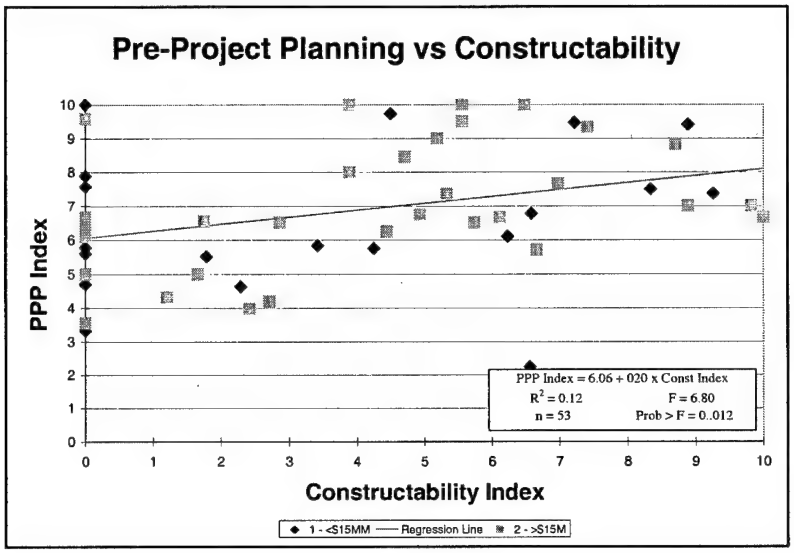


Figure 5.5 – Pre-project Planning versus Constructability Index

5.2.2.2 Team Building versus Constructability Index

The second analysis in this series looked at team building use versus constructability use. Figure 5.6 is the scatter-plot diagram showing all data points and the regression line. All 56 projects had appropriate data to be included in this analysis.

Statistically the relationships in this data set are not significant, but the upward trend in the regression line led to further investigation into the relationship in quality practices. The project cost breakdown did not prove insightful, however, a visual review of the indices showed a potential relationship within the owner and contractor projects. It seemed that higher constructability

use matched with higher pre-project planning use in the owner projects and higher constructability use matched with higher team building use for contractor projects. This visual interpretation of the data led to further regression analysis of just owner projects and then just contractor projects.

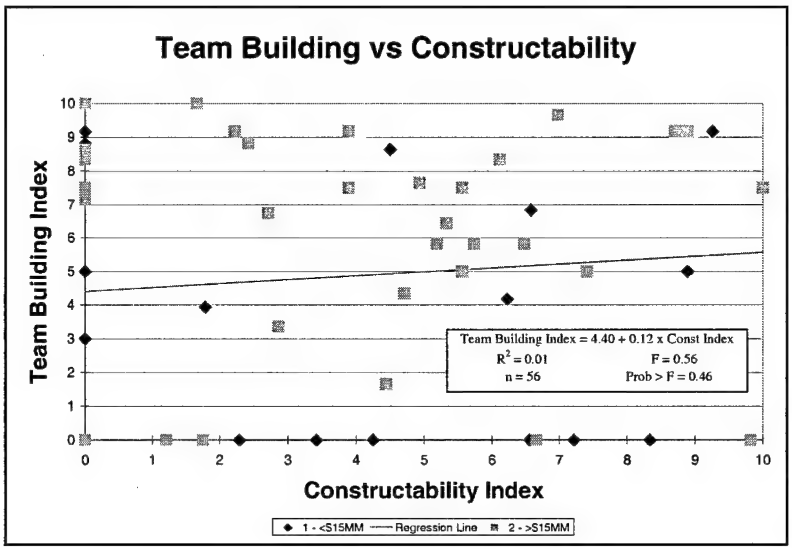


Figure 5.6 – Team Building versus Constructability Index

5.2.2.3 Owner Quality Practices versus Constructability Index

This analysis covered only the 40 owner projects in the data set. The use of pre-project planning and team building versus constructability use was examined. Figure 5.7 is the scatter-plot diagram showing owner project data points and the regression line for pre-project planning versus constructability use.

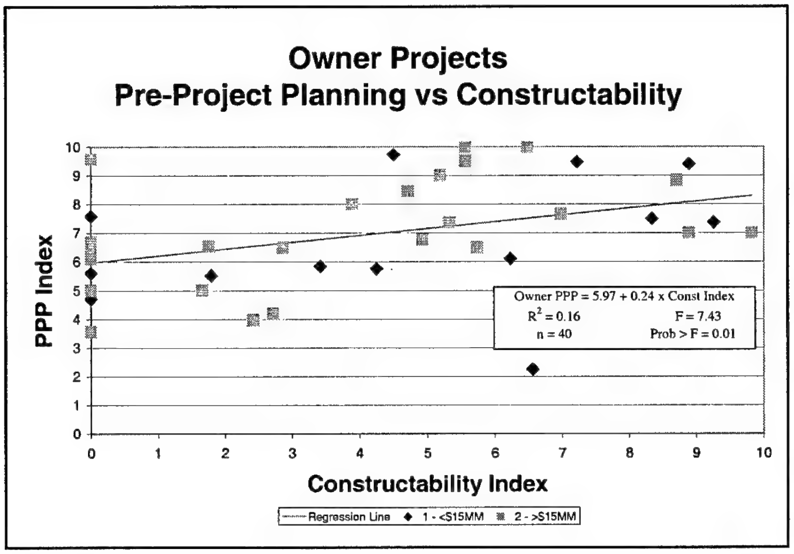


Figure 5.7 – Owner Pre-project Planning versus Constructability Index

With a strong correlation coefficient and minimum variance ratio, the relationship in this data set is statistically significant. This relationship is interpreted to verify owners in this data set use constructability to enhance project planning. In addition, the relationship substantiates constructability's use as a catalyst for further quality improvement and increased project success.

The regression analysis for owner team building use versus constructability use did not provide any meaningful statistical or interpreted results.

5.2.2.4 Contractor Quality Practices versus Constructability Index

This analysis attempted to reveal similar relationships in pre-project planning and team building use versus constructability use, but looked only at contractor data. The analysis included the 16-contractor projects from the original

data set; again records were removed if data was not available. A total of 13 projects were used in the pre-project planning analysis and all 16 projects for team building. In contrast to the relationship found in the owner data, contractor projects showed opposite results. Figure 5.8 is the scatter-plot diagram showing all the contractor data points and the regression line for team building versus constructability use.

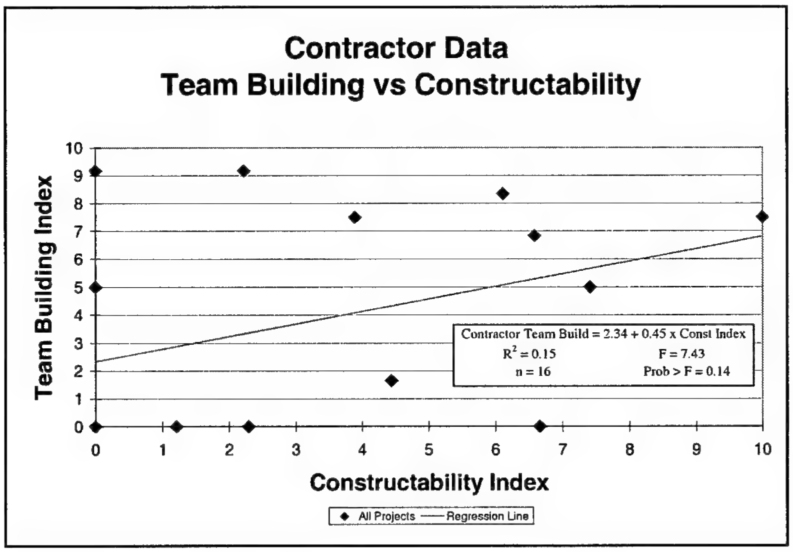


Figure 5.8 – Contractor Team Building Index versus Constructability Index

Statistically, the relationship in this analysis is significant; constructability use is correlated with team building use for contractor projects in this data set. Despite being a small data set, this relationship is interpreted to further illustrate constructability's use as a catalyst for quality improvement during the project process.

The contractor relationship between constructability and team building and the owner relationship between constructability and pre-project planning in

conjunction with mostly lump sum contracts in the data set suggests that the degree of constructability implementation is still minimal. Normally on lump sum bid contracts the owner and designer are more involved in pre-project planning and contractors involvement does not begin until the construction phase when team building activities are implemented. Although the data shows constructability is being used on the majority of the projects in this data set, some efforts begin later in the project when constructability suggestions are harder to implement and provide less influence on project success.

5.3 DISCUSSION

This chapter highlighted the most significant findings regarding constructability's affect on project performance and other best practices in 58 buildings projects from the BM&M Database. Although the results lack overwhelming statistical support, overall the relationships and trends in the data champion constructability as an improvement tool for projects in the building sector. The statistically moderate correlation between both schedule growth and RIR versus constructability use verifies constructability's positive influence on project performance. In addition, the positive trend of decreasing LWCIR with increasing constructability use provides further support to the relationship between constructability and improved project performance. Also, moderate correlation in both pre-project planning and team building use versus constructability use verifies constructability's role in project quality improvement.

Although the results discovered in this research are supportive of constructability's use in the building sector, specific application of results should be done with concern for limitations in the data set.

All data in the data set is provided by CII member companies and therefore, represents projects from leading owners, designers, and contractors focused primarily in heavy industrial construction. In addition, the project data submitted is from company-chosen projects and potentially represents better-than-average project results. Although CII policy attempts to eliminate this problem, comparing project results with industry competitors, even under academic intentions, still places some bias in the project submission process.

An additional limitation in the data set is the narrow use of performance measures. Although cost, schedule, and safety are normally key factors in project success, they do not represent success for all aspects of a project and for all members in the process.

Also, the indices for constructability, pre-project planning, and team building use, calculated from the practice element questions in the BM&M Questionnaire, may not provide a sufficient variation between projects with outstanding implementation and those with minimal implementation.

Although these limitations affect the application of the specific value of cost, schedule, and safety savings represented by this data set, they do not dispute the theme of constructability as an avenue for project improvement or as a positive influence on other quality improvement practices.

Chapter 6: Constructability Observations From A Typical Building Project

The constructability and related issues presented in this chapter represent observations from an $18.5 million grass-roots community college project. A more detailed discussion of the project and the author's participation in the project is presented in Chapter 3. The intent in gathering this data was to discover the potential existence and need for more formalized constructability efforts on building projects. It was not intended to be a comprehensive constructability analysis or a critique of the individuals or companies involved in managing or constructing the project. Although these observations are only anecdotal from a research perspective, they do provide specific examples of constructability opportunities on a typical building project.

Some bias does exist in the observations in favor of the general contractor because the majority of the constructability discussions took place with the general contractor's employees or subcontractors. For the purpose of this thesis, however, the benefits are in the existence of constructability related observations, not specifically in where or how constructability should have been applied on the project. The following observations attempt to summarize concepts or improvement ideas and then illustrate them through examples from the project. They are broken down into three categories: Design and Construction Coordination, Field Improvements, and Management Techniques.

6.1 Design and Construction Coordination

The design and construction coordination observations are opportunities to benefit project costs and schedule by improving project designs, material selections, craftsmen productivity, and safety. These observations require an increase in designer and contractor interaction.

- ***Shop drawings should be developed with the proper engineering information to explain where details tie into the project systems.***

For example, details in the shop drawings for handrails did not specify where the handrails would be located on the project. This problem caused additional coordination from field staff and the potential for incorrect installation and unproductive re-work.

- ***Site use issues are an important part of construction planning and should be considered as early as initial project layout.***

It is important to understand the constraints caused by limited or unplanned material storage and laydown areas. For example: The contractor on this project used a parking lot to store subbase material for all the site's sidewalks and the stormwater runoff containment system. Delays on other parts of the project compacted the schedule and required the sidewalk work and parking lot curbing and asphalt work to be completed simultaneously. This change required the material to be double handling, moving it to another storage location before placed as sidewalk subbase.

- ***Projects that require construction phasing need to address potential construction concerns early in project planning and design.***

For example: Although this project was built on a large site, the site was dense with trees. The owners environmental and architectural concerns allowed minimal tree removal creating worksite access concerns and material storage problems. Although the parking lots provided initial material storage and contractor parking needs, the phasing of the project determined during design, called for the initial turnover of the Academic Building, Central Plant, and all parking areas. The initial phasing plan lacked concern for how the contractor would continue to access following phases of the project, where material could be stored, and where construction craftsmen would park.

- ***Selection of architectural finishes should consider the level of difficulty for installation.***

Selection of finish type and installation details can create situations requiring extreme amounts of coordination effort between suppliers and subcontractors. There were several examples on this project where the architectural finishes should have considered construction impact to reduce costs, rework, and increased coordination effort.

    - The architectural design of the building corridors specified two layers of sheetrock to allow for a half inch wide reveal at the top of the wall, six inches below the drop ceiling. This detail required considerably more material and labor costs to install the second layer of sheetrock

and the metal reveal. In addition, it required more effort from the painters to tape and float around the detail and then paint it a different color.

- Interior finishes in all the rooms and corridors of the three buildings included painted concrete structural columns. This decision effects construction's choice of material and installation methods. Additional care was required during concrete pouring and adjacent drywall installation while a concrete finisher was necessary to rub all columns in preparation for painting. The architect should be aware of the effect of such a decision and the contractor should choose proper installation methods to minimize the amount of man-hours required to prepare a finish-quality concrete column.
- The exterior finish of the buildings was a combination of brickwork, cast stone, and metal handrails. The design detail for the handrails required welded connections at weld-plates in the concrete, but through a pre-formed hole in the cast stone. This detail forced the use of an awkward installation method. The large cast stone pieces, averaging 4' long, 1' wide, and 4" thick, needed to be set in place and then blocked up to weld the handrails. The detail of the handrails only provided a 8" open space at the bottom, thus, allowing only 2"-3" of working space for the welder. This installation method was required on almost 30 different handrail/cost stone locations with four plus welds in each case.

- ***Structural designs should consider the methods required for construction.***

On this project, the building foundations were designed as round concrete piers with square pier caps for connection to grade level beams and girders. In combination with the selected grades of the building and poor soil information, the contractor was required to remove significant amounts of rock from each pier location to allow forming of the pier caps. The contractor was under the impression that the site contained 1' to 3' of organic soil over limestone bedrock. However, in the majority of pier locations, only 6" of soil covered the limestone and the contractor required additional equipment and labor to remove rock for the pier caps to meet grading specifications. Early designer/contractor coordination could have addressed this problem with changes in design or site grading before manpower, equipment, and material were on site. A better understanding of the construction effects of design and by addressing them in the specifications could have alleviated the adversarial atmosphere on this project that resulted from this construction problem and eliminated the pending claim on this issue.

- ***Large savings potential can be found by employing construction review and input to contract specifications.***

Informal discussions with site personnel revealed that on another project a designer used general plastering specifications developed by the Architectural Institute of America (AIA). These specifications required the use of a special

installation method not required by Texas state law and not affecting final product quality, but amounted to an additional $28,000 in the price of the work.

- ***Continuing improvements in computers and communication systems have increased the importance of telecommunications in building design and construction.***

Computer and communications systems importance to the overall facility usefulness requires the early consideration of their construction needs. Coordination with the manufacturers and installers of these systems is needed to ensure the proper space, climate control, and user interfaces are provided. On this project, the electricians installed the necessary conduit and 4" electrical boxes with 2" reducing plates for telecommunication outlets as specified in the contract. However, a telecommunications contract was bid at a later date and required tie-ins to 4" box openings. By the time the problem was discovered the electricians had already expended the labor to install the reducers, the carpenters had already sheetrocked around them, and the painters had taped, floated, and painted the walls. In addition, the size of the specified telecommunication faceplates, already on order, would not cover a routed out opening to expose the 4" box. The final fix would require multiple drywall patches at all the telecommunication outlet in the Academic Building.

- ***Ensure architectural and structural drawings are well coordinated.***

In general, construction contractors use structural drawings to plan and perform materials take-off. Therefore, they rely on these drawings for bid

purpose and material purchase. On this project, the exterior architectural feature around both floors of the Learning Center Building required a metal stud frame and decking to support a continuous caststone shelf. Although present on the architectural drawings, the metal stud frame and decking were not on the structural drawings and, therefore, neither the general contractor nor any of the subcontractors picked this work up during bidding or material ordering. Even though contractually contractors are required to use construction documents as an entire entity, integration of construction expertise in the design process can identify common practices such as reliance on structural drawings and ensure that design work is well coordinated to eliminate potential claims and disputes.

6.2 SUGGESTED FIELD IMPROVEMENTS

The suggested field improvement observations are opportunities for the contractor to improve the construction activities by increasing planning, coordination, and concern for the craftsmen. These opportunities save time and money by improving productivity and minimizing safety hazards.

- ***Coordinating scaffolding needs on a project decreases site congestion and overall project cost, while improving productivity and safety.***

Allowing each trade to provide its own elevation system causes site congestion, unnecessary delays, and potential unproductive work methods. In addition, the risk of OSHA violations or the possibility of serious injury can be avoided.

- ***The health and welfare of craftsmen is important to productivity and quality.***

Activities such as providing sufficient drinking water and possibly products like Gatorade keep workers hydrated and more physically and mentally ready. In addition, providing for enough bathroom space and hand washing areas would ensure proper sanitation habits and minimize the potential for illnesses thereby keeping craftsmen on the construction site. In hot weather environments ample, shaded rest areas should also be considered.

- ***Wire-mess stabilized silt fencing provides a containment system that requires less maintenance to upkeep while also improving the site aesthetics.***

Hiring contractors specialized in the installation of silt containment systems can increase the useful life and effectiveness of the silt fencing and minimize upkeep and maintenance requirements.

- ***The various tasks within a work package should be coordinated and specific sequencing requirements should be addressed in the drawings and specifications.***

Detailed planning and coordination of work sequencing are essential prior to starting work to ensure good productivity and minimize rework. On this project, the construction of the cooling tower was done out of sequence according to the owner/architect and completed work was rejected during inspection. The

installation sequence consisted of forming the basin, pouring and finishing the concrete, erecting the wooden support structure, installing mechanical equipment, and applying epoxy paint to the concrete basin. The owner/architect felt the application of epoxy paint was not according to specifications because it was done last instead of before the erection of the support structure. Rethinking the work sequence by the contractor or specific requirements detailed in the specifications by the designer could have prevented the problem and the need for two additional applications of epoxy paint in a cramped, unproductive workspace.

- ***A clean and organized work site enhances construction efficiency and productivity.***

It is important to plan for proper trash disposal and have sufficient trashcans for regular trash as well as construction debris. Provide an appropriate dumping schedule to keep trash containers from overflowing or going unused. Consider location for large trash dumpsters during construction site layout to minimize interference with construction activities, but continue to invite use as a disposal site.

- ***Footing and wall connections should be designed for easy coordination between various craftsmen in the field.***

For example, construction efforts should ensure the proper coordination between footing rebar placement and Concrete Masonry Unit (CMU) patterns. On this project, a CMU wall was designed to conceal mechanical equipment and

delivery ramps at the Central Plant. The wall seemed over designed with a 3'-wide spread footing and #8-rebar, 3' feet high as the connection. The rebar was installed slightly off center requiring the mason to cut each CMU block in the first 3' of wall to fit around the rebar. This problem could have been solved during design with a more simple detail, however, the problem was compounded during construction when the proper level of coordination was not performed.

- ***Project policies should be thoroughly developed and planned early and enforced from the beginning.***

Employees should be educated about the existence of and rational behind the project policies. On this project, the contractor, as specified by the owner, provided a centralized contractor employee parking area. The various subcontractors' employees were expected to park personal vehicles in this parking lot, but little was done to those who violated the policy. As a result of the extreme summer heat, vehicles were parked closer to work areas to be under the shade of trees. Fearing damage to the trees and surrounding underbrush (a dominant feature of the final site architecture) the owner identified the problem and demanded enforcement of the parking policy. After almost 8 months of going unpunished for their parking habits, it was extremely difficult to get violators to return to the approved parking area. Limited control of subcontractors, employee dispersion over the site, and the legal and cost ramifications of towing, created problems identifying offenders and providing ample punishment. One recommendation, suggested by the field architect, was to use violation stickers

describing the parking policy and attach them to the middle of the drivers-side of the windshield.

6.3 MANAGEMENT TECHNIQUES

The management technique observations are opportunities for project improvement through utilization of qualified personnel and well-defined and employed management tools.

- ***It is vital for a project to have competent, professional management personnel on all sides.***

Individuals need to be knowledgeable not only in the technical aspects of the project, they must understand how the construction process will work physically and administratively and realize the owner's project goals and objectives. They need to possess the coordination and communication skills to tie the different parts and people in the project together. Finally, they must empower their employees to complete the project tasks they are assigned. The numbers of tasks needed to manage a project are overwhelming for one individual and delegation and empowerment are the keys to success.

- ***Submittals are an important part of good materials management.***

Ensure good communication channels are established with the owner and architect to quickly work substitutions and re-submittals. Waiting for the paper trail to receive disapproved submittals can cause unnecessary delays and costs.

On lump sum, competitively bid projects, where the contractor has minimal influence on material selections, it may help to investigate previous projects completed by the owner to ensure substitutions are even viable. Even though the contract is competitive in nature, the owner is often looking for similar products used on previous projects to minimize maintenance requirements.

- ***Project meetings are an important planning and problem-solving tool.***

  Therefore, it is extremely important to have the right people involved with the appropriate authority in project meetings. Using these venues to expose potential problems and get resolution prior to impacting the project is vital. For example, additional meeting forums like an Air Conditioning Commissioning Meeting bring the necessary individuals together to ensure problems are solved early and all work accomplished on the system is done correctly the first time.

- ***Construction input to field clarifications or changes is essential.***

  Field clarifications or changes are the first time projects without constructability programs allow direct contractor influence on how work will be specified and accomplished. It is necessary for the contractor to remain involved with information received from designer clarifications and the revised scope of work defined by changes to ensure construction sensitive methods and materials are used to minimize potential delays and unnecessary rework

- ***The use of a well-defined change-pricing format can speed up the change order process and minimize administrative costs and potential construction delays.***

On this project there seemed to be a considerable misunderstanding in exactly what the architect/owner deemed a properly detailed estimate. Prior planning on this issue could have saved the architect/owner and the contractor time and money by deliberately explaining and providing examples of how change orders were to be priced. The ill will and mistrust developed during change order re-works and negotiations created a hostile working relationship that affected other parts of the job.

Chapter 7: Conclusions and Recommendations

In the future, customers of the construction industry will continue to demand projects that cost less, finish faster, and are of better quality. As owners align business goals with construction requirements, pressure to meet customer needs and expectations will force companies involved in the construction industry to use continuous quality improvement to stay in business. The topic of this thesis, "Constructability", is a quality improvement tool first acknowledged by industry leaders in the early 1980's. Those companies realized the troubled relationship between designers and constructors and understood the huge potential for increasing project success by improving communication between the parties. Research into and implementation of constructability lead to immediate and substantiated proof that potential improvements in construction existed. Despite these documented successes involving construction knowledge and expertise, much of the construction industry has not explored or implemented the ideas behind constructability. For reasons of lacking knowledge or skepticism in its effectiveness, constructability tools have often gone unused by the industry, particularly in building projects.

7.1 Purpose Review

As stated in Chapter 1, the purpose of this thesis was to explore the use of constructability as a potential avenue for improvement in building projects. The intent of the research was to meet the following objectives:

- Review the use of constructability as a continuous quality improvement tool.
- Discover the applicability of constructability on building projects.
- Investigate constructability's affect on building project performance, specifically cost growth, schedule growth, and safety use.
- Investigate constructability as a catalyst for continuous improvement, specifically showing its influence on pre-project planning and team building.
- Provide further analysis of the Construction Industry Institute (CII) Benchmarking and Metrics (BM&M) Database

7.2 RESEARCH CONCLUSIONS

Results drawn from data analysis of 58 building projects combined with observations made during a field study have met these objectives. The following conclusions were developed from this research.

- Current project processes during all phases of building projects have opportunities for improvement.
- Improvement opportunities on building projects can be exploited through implementation of constructability ideas and concepts.
- Constructability is continuous quality improvement and a viable construction improvement tool for use on building projects.

- Developing a project atmosphere focused on how decisions affect construction also increases awareness of planning requirements, improves teamwork, and leads to more productive work.
- Increased constructability use on building projects in the data set showed downward trends in the value of schedule growth and better control of that schedule growth. Although not statistically significant, owners would be interested in the potential 26 percent improvement in schedule growth interpreted from a no constructability use (0) to a maximum constructability use (10) on the CII index scale.
- Increased constructability use on building projects in the data set correlated to positive trends in safety performance. The data set showed a statistically significant decrease in the Recordable Incident Rate (RIR) for an increase on the constructability index. Also, a positive performance trend was seen in the relationship between Lost Workday Case Incident Rate (LWCIR) and constructability use for the data set.
- Owners using constructability as an improvement tool also use pre-project planning to a similar degree. Contractors using constructability use team building to a similar degree.

7.3 Recommendations for Further Research

As with most research, the questions answered are far fewer than the questions discovered. This thesis touches the surface of constructability in building projects. Further review of the data collection tools for this thesis and

more specific research into implementation of constructability in building projects could be performed. The following examples are potential avenues for further research into the use of constructability on building projects.

- Develop a specific implementation tool designed for the difficulties inherent in building projects, i.e. more rigid contracts, less contractor influence, limited role of general contractors.
- Investigate improving the CII Constructability Index Measure. Are the questions used to measure the constructability index equal in value or should some weigh more heavily on the value of the index? Are these the right questions to be asking in the first place? Or should the questions be revised to better suit differences in building projects?
- Attempt a constructability implementation case study on an average building project. Will the project success results discovered during previous research, cost and schedule reductions and improved safety, hold true on less complex, cheaper projects or just projects with extreme circumstances?
- Is there a relationship between the CII Best Practice Indices? Can they be combined for an overall quality assessment? Or do aspects of each have bearing on the value of the others?

Appendix A: BM&M Questionnaire, Version 2 - Owner

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

The data collected by this form begins the second round of data collection for CII's benchmarking and metrics system. The data will be used to establish performance norms, to identify trends, and to correlate execution of project management processes to project outcomes. It will form part of a permanent database. Through such correlation across many companies and projects, opportunities for improving your company's project performance will be identified. CII will not analyze performance of individual companies, however. Each company will be provided the means to compare itself to the benchmarks. Therefore, it is important that you retain a copy of this questionnaire for your records. **All data will be held in strict confidence**.

When you have completed the questionnaire, please return it to your Company's Data Liaison by **May 1, 1997**.

The next 2 pages contain definitions for project phases. Please pay particular attention to the start and stop points which have been highlighted. All project costs should be given in U.S. dollars. If you need further assistance in interpreting the intent of a question, please call Ned Givens or Kirk Morrow of CII at (512) 471-4319 (E-mail: tkmorrow@mail.utexas.edu). Remember, conformance to the instructions and phase definitions is crucial for establishing reliable benchmarks.

Your company data liaison has been provided with a list of projects which were submitted by your company during the previous data collection effort. In order to maintain the integrity of the database, please ensure that projects which have been submitted previously are not reported again.

If the information required to answer a given question is not available, please write "UNK" (unknown) in the space provided. If the information requested does not apply to this project, please write "NA" (not applicable) in the space provided. However, keep in mind that too many "unknowns" or "not applicables" could render the project unusable for analysis.

This form should be completed under the direction of the project manager. The project manager should consult with colleagues who worked on the project. We urge that you carefully review the phase table on the next 2 pages before attempting to provide the requested information.

Definition is provided in the attached glossary for words and phrases that are both italicized and underlined.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Project Phase Table

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Pre-Project Planning Typical Participants: • Owner personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning team personnel expenses • Consultant fees & expenses • Environmental Permitting costs • Project Manager / Construction Manager fees • Licensor Costs
Detail Design Typical Participants: • Owner personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & spec preparation • Bill of material preparation • Procurement Status • Sequence of operations • Technical Review • Definitive Cost Estimate	• Owner project management personnel • Designer fees • Project Manager / Construction Manager fees
Demolition / Abatement (see note below) Typical Participants: • Owner personnel • General Contractor • Demolition Contractor • Remediation / Abatement Contractor	**Start: Mobilization for demolition** <u>Stop: Completion of demolition</u>	• Remove existing facility or portion of facility to allow construction or renovation to proceed • Perform cleanup or abatement / remediation	• Owner project management personnel • Project Manager / Construction Manager fees • General Contractor and/or Demolition specialist charges • Abatement / remediation contractor charges

Note: The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not use the demolition / abatement phase if the work is integral with modernization or addition activities.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Project Phase Table (Cont.)

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Procurement Typical Participants: • Owner personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Vendor Qualification • Vendor Inquiries • Bid Analysis • Purchasing • Expediting • Engineered Equipment • Transportation • Vendor QA/QC	• Owner project management personnel • Project Manager / Construction Manager fees • Procurement & Expediting personnel • Engineered Equipment • Transportation • Shop QA / QC
Construction Typical Participants: • Owner personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	**Start: Beginning of continuous substantial construction activity** **Stop: *Mechanical Completion***	• Set up trailers • Site preparation • Procurement of bulks • Issue Subcontracts • Const plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize construction equipment • Warehousing	• Owner project management personnel • Project Manager / Construction Manager fees • Building permits • Inspection QA/QC • Construction labor, equipment & supplies • Bulk materials • Construction equipment • Contractor management personnel • Warranties
Start-up / Commissioning Note: Does not usually apply to infrastructure or building type projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Vendors	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and obtain Product • Hand-off to user/operator • Operating System • Functional Facility • Warranty Work	• Owner project management personnel • Project Manager / Construction Manager fees • Consultant fees & expenses • Operator training expenses • Wasted feedstocks • Vendor fees

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

1. Your Company: ____

2. Your Project I.D. ____
(You may use any reference to protect the project's identity. The purpose of this I.D. is to help you and CII personnel identify the questionnaire correctly if clarification of data is needed and to prevent duplicate project entries.)

3. Project Location: Domestic ______________________, USA
State
International ______________________
Country

4. Contact Person (name of the person filling out this form): ______________

5. Contact Phone No. (   ) __________ **6.** Contact Fax No. (   ) __________

7. Principal Type of Project (Check only one. If you feel the project does not have a principal type, but is an even mixture of two or more of those listed, please attach a short description of the project. If the project type does not appear in the list, please describe in the space next to "Other."):

Industrial	Infrastructure	Buildings
___Electrical (Generating)	___Electrical Distribution	___Lowrise Office
___Oil Exploration/Production	___Highway	___Highrise Office
___Oil Refining	___Navigation	___Warehouse
___Pulp and Paper	___Flood Control	___Hospital
___Chemical Mfg.	___Rail	___Laboratory
___Environmental	___Water/Wastewater	___School
___Pharmaceuticals Mfg.	___ Airport	___Prison
___Metals Refining/Processing	___Tunneling	___Hotel
___Microelectronics Mfg	___Marine Facilities	___Maint Facilities
___Consumer Products Mfg.	___Mining	___Parking Garage
___Natural Gas Processing		___Retail
___Automotive Mfg.		
___Foods		

______Other(Please describe)________________________________

____

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

8. This project was (check one): Grass Roots___ Modernization ___ Addition ___

Grass roots - a new facility from the foundations and up. A project requiring demolition of an existing facility before new construction begins is also classified as grass roots.

Modernization - a facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility.

Addition - a new addition that ties in to an existing facility, often intended to expand capacity.

_____ Other (Please describe)________________________________

____

9. Achieving Design Basis. Please indicate in the following table the product or function of the completed facility, the unit of measure which best relates the product or function capacity of the completed facility, the planned capacity of the facility at the start of detail design, and the capacity achieved by the completed facility.

For process facilities, the measure is either one of input or output as appropriate. Examples : crude oil refining unit - barrels per day throughput

For infrastructure or buildings, please include the measure that you feel is best. Please spell out this measure rather than using an abbreviation.

If the product produced or function provided by this facility is of a confidential nature, please write "Confidential" in the first column and provide the other data.

If you are unable to furnish a measure or units, please write "NA" (not applicable) in the "Product or Function" field and go to question 10.

Product or Function	Unit of Measure	Planned Start-up Capacity	Achieved Start-up Capacity	Planned Final Capacity	Achieved Final Capacity

9a. Please indicate the method of ***acceptance testing*** used on this project.

_____ No Assessment

_____ Demonstrated operations at achieved level

_____ Formal documented acceptance test over a meaningful period of time

9b. Please indicate how the achieved capacity of the completed facility compares against expectations documented in the project execution plan. If the achieved capacity is much worse or much better than expected, please briefly comment on the primary cause of the deviation.

_____ Much worse than expected Why? ____________________

_____ Worse than expected ______________________________

_____ As expected

_____ Better than expected

_____ Much better than expected Why? ____________________

____

10. Project Participants. Please list the companies, including your company, that helped execute this project, but do not list any subcontractors. Indicate the function(s) each company performed and the approximate percent of that function to the nearest 10%. For each function, indicate the principle form of remuneration in use at the completion of the work. Please indicate if each participant was an alliance partner and if their contract contained incentives.

Please use the following codes to identify the **Function** performed by each project participant.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

PPP	Pre-Project Planner	DM	Demolition/Abatement Contractor
PPC	Pre-ProjectPlanning Consultant	GC	General Contractor
D	Designer	PC	Prime Contractor
PE	Procurement - Equipment	PM	Project Manager
PB	Procurement - Bulks	CM	Construction Manager

Percent of Function refers to the percent of the overall function contributed by the company listed. Estimate to the nearest 10 percent.

Type of Remuneration refers to the overall method of payment. Unit price refers to a price for in place units of work and does not refer to hourly charges for skill categories or time card mark-ups. Hourly rate payment schedules should be categorized as cost reimbursable. Please use the following codes to identify remuneration type. Record the form of remuneration for your own company's contribution, if any, as "I" (In House).

LS	Lump Sum	GP	Guaranteed Maximum Price
UP	Unit Price	I	In-house
CR	Cost Reimbursable/Target Price (Including Incentives)		

An ***Alliance Partner*** is a company with whom your company has a long-term formal strategic agreement that ordinarily covers multiple projects. Circle "Y" to indicate that a company was an alliance partner or circle "N" if the company was not an alliance partner.

If **Contract Incentives** were utilized, please indicate whether those incentives were positive (a financial incentive for attaining an objective), negative (a financial disincentive for failure to achieve an objective), or both. Circle "+" to indicate a positive incentive and circle "-" to indicate a negative incentive.

Company Name	Function	Approx. Percent of Function (Nearest 10%)	Type of Remun. (Contract End)	Was this company an alliance partner? (Yes/No)		Contract Incentives (circle as many as apply)							
						Cost		Schedu le		Safety		Quality	
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-

11a. ***Total Project Budget***

- The total project budget amount should correspond to the estimate at the start of detail design including ***contingency***.
- The total project budget amount should include all planned expenses from pre-project planning through startup or to a "ready for use" condition, excluding the ***cost of land***.
- State the project budget in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$______________________________

11b. How much ***contingency*** does this budget contain? (to the nearest $1000. You may use a "k" to indicate thousands in lieu of "...,000".)

$______________________________

12. ***Total Actual Project Cost*:**

- The total actual project cost should include all actual project costs from pre-project planning through startup or to a "ready for use" condition, excluding the cost of land.
- Actual costs should correspond to those that were part of the budget. For example, if the budget included specific amounts for in-house personnel, then actual cost should include the actual amounts expended during the project for their salaries, overhead, travel, etc.
- State the project cost in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$______________________________

13. Please indicate the budgeted and actual costs by project phase

- Phase budget amounts should correspond to the estimate at the start of detail design.
- Refer to the table on pages 2 and 3 for phase definitions and typical cost elements.
- State the phase costs in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)
- Include the cost of bulk materials in construction and the cost of engineered equipment in procurement.
- If this project did not involve Demolition/Abatement or Startup please write "NA" for those phases.
- The sum of phase budgets should equal the Total Project Budget and the sum of actual phase costs should equal Total Actual Project Cost from questions 11 & 12 above.

Project Phase	Phase Budget (Including Contingency)	Amount of Contingency in Budget	Actual Phase Cost
Pre-Project Planning	$	$	$
Detail Design	$	$	$
Procurement	$	$	$
Demolition/Abatement	$	$	$
Construction	$	$	$
Startup	$	$	$
Totals	$	$	$

14. Planned and Actual Project Schedule

- The dates for the planned schedule should be those in effect at the start of detail design. If you cannot provide an exact day for either the planned or actual, estimate to the nearest week in the form mm/dd/yy; for example, 1/8/96, 2/15/96, or 3/22/96.)
- Refer to the chart on pages 2 and 3 for a description of starting and stopping points for each Phase.
- If this project did not involve Demolition/Abatement or Startup please write "NA" for those phases.

Project Phase	Planned Schedule		Actual Schedule	
	Start mm / dd / yy	Stop mm / dd / yy	Start mm / dd / yy	Stop mm / dd / yy
Pre-Project Planning	/ /	/ /	/ /	/ /
Detail Design	/ /	/ /	/ /	/ /
Procurement	/ /	/ /	/ /	/ /
Demolition/Abatement	/ /	/ /	/ /	/ /
Construction	/ /	/ /	/ /	/ /
Startup	/ /	/ /	/ /	/ /

14a. What percentage of the total engineering workhours for design were completed prior to total project budget authorization? (Write "UNK" in the blank if you don't have this information)

__________ %

14b. What percentage of the total engineering workhours for design were completed prior to start of the construction phase? (Write "UNK" in the blank if you don't have this information)

__________ %

15. ***Project Development Changes*** and ***Scope Changes.*** Please record the changes to your project by phase in the table provided below. For each phase indicate the total number, the net cost impact, and the net schedule impact resulting from project development changes and scope changes. Changes may be initiated by either the owner or contractor.

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis.

Scope Changes include changes in the base scope of work or process basis.

- Changes should be included in the phase in which they were initiated. Refer to the table on pages 2 and 3 to help you decide how to classify the changes by project phase. If you cannot provide the requested change information by phase, but can provide the information for the total project please indicate the totals.
- Indicate "minus" (–) in front of cost or schedule values, if the net changes produced a reduction. If no changes were initiated during a phase, write "0" in the "Total Number" columns.
- State the cost of changes in U.S. dollars to the nearest $1000 and the schedule changes to the nearest week. You may use a "k" to indicate thousands in lieu of "...,000".

Project Phase	Total Number of Project Development Changes	Total Number of Scope Changes	Net Cost Impact of Project Development Changes ($)	Net Cost Impact of Scope Changes ($)	Net Schedule Impact of Project Development Changes (weeks)	Net Schedule Impact of Scope Changes (weeks)
Design			$	$	wks	wks
Procurement			$	$	wks	wks
Demolition/Abatement			$	$	wks	wks
Construction			$	$	wks	wks
Startup			$	$	wks	wks
Totals			$	$	wks	wks

16. Field Rework

Was there a system for tracking and evaluating field rework for this project?

_____ Yes _____ No

If yes, please complete the following table. If no, proceed to question 17.

Please indicate the Direct Cost of Field Rework, the Cost of Quality Management, and the Schedule Impact of Field Rework for each category shown in the following table. If you track field rework by a few other or additional categories, please add them in the blank spaces provided. If the system used on this project does not include any of the Sources of Field Rework listed, write "NA" (not applicable) in the Direct Cost of Field Rework space. If your system used a listed Source of Field Rework, but this project had no Field Rework attributable to it, write "0" in the Direct Cost of Field Rework space. If you cannot provide the requested field rework information by Source of Field Rework, but can provide the information for the total project, please write "UNK" (unknown) in the fields adjacent to the sources of field rework and indicate the totals.

The ***direct cost of field rework*** relates to all costs needed to perform the rework itself whereas the ***cost of quality management*** includes quality assurance or quality

control costs, which may identify the need to perform field rework or prevent the need for additional field rework.

Source of Field Rework	Direct Cost of Field Rework	Cost of Quality Management	Schedule Impact of Field Rework
Owner Change	$	$	Weeks
Design Error / Omission	$	$	Weeks
Designer Change	$	$	Weeks
Vendor Error / Omission	$	$	Weeks
Vendor Change	$	$	Weeks
Constructor Error / Omission	$	$	Weeks
Constructor Change	$	$	Weeks
Transportation Error	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
Totals	$	$	Weeks

17. Actual Total Cost of Major Equipment

Please record the actual total cost of major equipment procured for permanent installation in this project in the space provided below.

- Include only the invoiced cost for items of major equipment. Do not include the cost of associated services such as making vendor inquiries, analyzing vendor bids, or expediting.
- State the cost of equipment in U.S. dollars to the nearest $1000. You may use a "k" to indicate thousands in lieu of "...,000".
- Refer to the following table to help you identify major equipment expenditures.
- If the project did not include major equipment, which is typical of many infrastructure or building projects, please write "NA."

$ ____________________

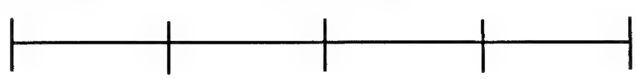
CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

General Classification	Kinds of Equipment Covered
Columns and Pressure Vessels (Code Design)	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks (non-code design; 0-15 psig, MAW or design pressure)	Atmospheric storage tanks, bins, hoppers, and silos.
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and cooling towers) - excludes fired heaters.
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Pumps	All types of liquid pumps and drivers.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum-producing apparatus and integral auxiliary equipment.
Turbines	
Motors	
Electricity Generation and Transmission	Major electrical items (e.g., transformers, switch gear, motor-control centers, batteries, battery chargers, and cable [15kV]).
Speed Reducers/Increasers	
Materials-Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, refrigeration systems, ion-exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, and other such machinery with their drivers.

17b. Project Complexity

Place a mark anywhere on the scale below that best describes the level of complexity for this project as compared to other projects from the same industry sector. For example, if this is a heavy industrial project, how does it compare in complexity to other heavy industrial projects. Use the definitions below the scale as general guidelines.

Low Complexity | Average Complexity | High Complexity



Low Complexity - Characterized by the use of no unproven technology, small number of process steps, small facility size or process capacity, previously used facility configuration or geometry, proven construction methods, etc.

High Complexity - Characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods, etc.

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18. Workhours and Accident Data

Please record total craft workhours, the number of recordable injuries, and the number of lost workday cases separately in the spaces provided below.

- Use the U.S. Department of Labor's OSHA definitions for recordable injuries and lost workday cases among this project's craft workers. If you do not track in accordance with these definitions, write "UNK" in the recordable injuries and lost workday cases columns.
- Write "UNK" in any space for which the information is unavailable or incomplete.
- A consolidated project OSHA 200 log is the best source for the data.

Total Craft Workhours	OSHA Recordable Injuries	OSHA Lost Workday Cases

18a. How many of the craft workhours reported in the table above were "overtime" (or "premium time")? (Write "UNK" in the blank if you don't have this information)

________________________ hrs

CII Benchmarking and Metrics
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Safety Practices

Safety includes the site-specific program and efforts to create a project environment and state of consciousness which embraces the concept that all accidents are preventable and that zero accidents is an obtainable goal. If this project was accident free, check "NA" as appropriate for questions 27 through 30.

	Yes	No	
19.	___	___	This project had a written site-specific safety plan.
20.	___	___	This project had a written site-specific emergency plan.
21.	___	___	This project had a site safety supervisor.
22.	___	___	The site safety supervisor for this project was full-time.
23.	___	___	This project had a written safety incentive program for hourly craft employees.
24.	___	___	Toolbox safety meetings were required.
25.	___	___	This project required prehire substance abuse testing of contractor employees.
26.	___	___	Contractor employees were randomly screened for alcohol and drugs.

27. Substance abuse tests were conducted after an accident:

_____ Always _____ Sometimes _____ Seldom _____ Never _____ NA

28. Accidents were formally investigated:

_____ Always _____ Sometimes _____ Seldom _____ Never _____ NA

29. Near-misses were formally investigated:

_____ Always _____ Sometimes _____ Seldom _____ Never _____ NA

30. Senior management reviewed accidents:

_____ Always _____ Sometimes _____ Seldom _____ Never _____ NA

CII Benchmarking and Metrics
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31. Safety was a high priority topic at all pre-construction and construction meetings:

_____ Always _____ Sometimes _____ Seldom _____ Never

32. Safety records were a criterion for contractor/subcontractor selection:

_____ Always _____ Sometimes _____ Seldom _____ Never

33. Pre-task planning for safety was conducted by contractor foremen:

_____ Always _____ Sometimes _____ Seldom _____ Never

34. Jobsite-specific orientation was conducted for new contractor and subcontractor employees:

_____ Always _____ Sometimes _____ Seldom _____ Never

35. This question is for Contractors only.

CII Benchmarking and Metrics
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Team Building Practices

Team Building is a process that brings together a diverse group of project participants and seeks to resolve differences, remove roadblocks and proactively build and develop the group into an aligned, focused and motivated work team that strives for a common mission and for shared goals, objectives and priorities.

36. Was a team building process used for this project? Yes _____ No ______

If yes, answer questions 36a - 36h. If no, go to question 37.

	Yes	No	
36a.	___	___	Was an independent consultant used to facilitate the team building process?
36b.	___	___	Was a team-building retreat held early in the life of the project?
36c.	___	___	Did this project have a documented team-building implementation plan?
36d.	___	___	Were objectives of the team building process documented and clearly defined?

36e. Were team building meetings held among team members throughout the project?

______ Regularly ______ Sometimes ______ Seldom ______ Never

36f. Were follow-up sessions held to integrate new team members and reinforce concepts?

______ Regularly ______ Sometimes ______ Seldom ______ Never

CII Benchmarking and Metrics
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36g. Please indicate the project phases in which team building was used. (Check all that apply)

____ Pre-Project Planning
____ Design
____ Procurement
____ Construction
____ Startup

36h. Please indicate the parties involved in the team building process. (Check all that apply)

____ Owner
____ Designer(s)
____ Contractor(s)
____ Major Suppliers
____ Subcontractor(s)
____ Construction Manager
____ Other. If other, please specify________________________________
____

Constructability Practices

Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Constructability is achieved through the effective and timely integration of construction input into planning and design as well as field operations.

37. Was Constructability implemented on this project? Yes ____ No ____

If yes, please respond to the following statements (37a-37l). If no, go to question 38.

37a. Which of the following best describes the constructability program designation for this project?

____ No designation
____ Part of standard construction management activities
____ Part of another program, such as Quality or only identified on a project level
____ Recognized on a corporate level, but may be part of another program
____ Stand-alone program on same level as Quality or Safety

37b. Which of the following best describes the constructability training of personnel for this project?

____ None
____ If any occurs, done as on-the-job training
____ Awareness seminar(s)
____ Part of standard orientation
____ Part of standard orientation; deeply ingrained in corporate culture

37c. Which of the following best describes the role of the constructability coordinator for this project?

____ Coordinator not identified
____ Part-time if identified; very limited responsibility
____ Informal full- or part-time position; responsibilities vary
____ Formal full- or part-time position; responsibilities vary
____ Full-time position; plays major project role

37d. Which of the following best describes the constructability program documentation for this project?

____ None; CII documents may be available
____ Limited reference in any manual; CII documents may be distributed or referenced
____ Project-level constructability documents exist; may be included in other corporate documents
____ Project constructability manual is available
____ Project constructability manual is thorough, widely distributed, and periodically updated

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project?

____ None
____ Reactive approach, constrained by review mentality, poor understanding of proactive benefit
____ Aware of major benefits, proactive approach
____ Proactive approach; routinely consult lessons learned
____ Aggressive, proactive approach from beginning of project; routinely consult lessons learned

37f. Which of the following best describes the implementation of constructability concepts on this project?

____ Very little concept implementation
____ Some concepts used periodically; often considered too late to be of use
____ Selected concepts applied regularly; full use, timeliness of input varies
____ All concepts consistently considered; timely implementation of feasible concepts
____ All concepts consistently considered, continuously evaluated, aggressively implemented

37g. Constructability ideas on this project were collected by: (Check as many as apply)

_____ Suggestion Box
_____ Interviews
_____ Review Meetings
_____ Questionnaire
_____ Other Methods ______________________________
_____ Not Collected

37h. To what extent was a computerized constructability database utilized for this project?

_____ None
_____ Minimal
_____ Moderate
_____ Extensive

37i. Please characterize the frequency of the constructability reviews and discussions for this project.

_____ Once a Week
_____ Once a Month
_____ Once every 3 Months
_____ Once every 6 Months
_____ Once a Year or Less Frequent

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability. Place a check below the appropriate period.

Pre-Project Planning			Detail Design/Procurement			Construction		
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late

Yes No

37k. ___ ___ Constructability was an element addressed in this project's formal written execution plan.

37l. ___ ___ Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?

If yes, please list? $ _________________

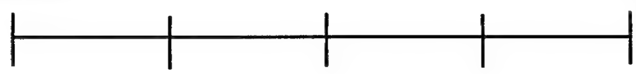
CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Pre-Project Planning Practices

Pre-Project Planning involves the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning. Please respond to the following statements using the definition provided below the scale for guidance (Questions 38a - 38d are for Contractors only.)

38e. Place a mark on the scale below that best describes the composition of the pre-project planning team.

Excellent Poor



Excellent - Highly skilled and experienced members with authority; representation from business, project management, technical disciplines, and operations; able to respond to both business and project objectives.

Poor - Members with a poor combination of skill or experience that lack authority; insufficient representation from business, project management, technical disciplines, and operations; unable to respond to both business and project objectives.

38f. Place a mark on the scale below that best describes the technology evaluation for this project.

Excellent Poor

Excellent - Thorough and detailed identification and analysis of existing and emerging technologies for feasibility and compatibility with corporate business and operations objectives. Scale-up problems and hands-on process experience were considered.

Poor - Poor or no technology evaluation.

38g. Place a mark on the scale below that best describes the evaluation of alternate siting locations.

Excellent Poor

Excellent - Thorough and detailed assessment of relative strengths and weaknesses of alternate locations to meet owner requirements.

Poor - Poor or no evaluation of alternate siting locations.

38h. Place a mark on the scale below that best describes the risk analysis performed for project alternatives.

Excellent Poor

Excellent - Risks associated with the selected project alternatives were identified and analyzed. These analyses included financial/business, regulatory, project, and operational risk categories in order to minimize the impacts of risks on project success.

Poor - Poor or no risk analysis performed for project alternatives.

The Project Definition Rating Index (PDRI) identifies and describes critical elements in a scope definition package and allows a project team to predict factors impacting project risk. It is intended to evaluate the completeness of <u>project scope definition</u> prior to consideration for authorization.

39. Was the Project Definition Rating Index (PDRI) utilized on this project? __yes__no

If yes, indicate the score received just prior to total project budget authorization.

____

Please attach a copy of the PDRI scoresheet and proceed to question 40.

If no, please complete the following matrix using the appropriate definition levels given below. Definition is provided for each of the pre-project planning elements on pages 4 through 11 of the glossary of terms. <u>Indicate how well defined each element was prior to the total project budget authorization by placing a check below the appropriate definition</u>

level. Elements with definition levels 2 through 4 darkened should be answered as "yes/no" questions. Indicate definition level 1 for "yes" or definition level 5 for "no" to indicate if the elements either existed or did not exist within the project definition package at authorization.Definition Levels:

1 - Complete definition 3 - Some deficiencies 5 - Incomplete or poor definition
2 - Minor deficiencies 4 - Major deficiencies N/A - Not applicable

Note: If the project on which you are reporting is a building or infrastructure project, some of the following elements may not apply to your project. Please place a check in the "N/A" column to indicate "not applicable" if any element does not apply to your project.

	Definition Level at Authorization					
	Complete ←→ Poor					
Technical Elements	1	2	3	4	5	N/A
a. Process Flow Sheets						
b. Site Location						
c. P&ID's						
d. Heat & Material Balances						
e. Environmental Assessment						
f. Utility Sources With Supply Conditions						
g. Mechanical Equipment List						
h. Specifications - Process/Mechanical						
i. Plot Plan						
j. Equipment Status						
Business Elements						
k. Products						
l. Capacities						
m. Technology						
n. Processes						
o. Site Characteristics Available vs. Req'rd						
p. Market Strategy						
q. Project Objectives Statement						
r. Project Strategy						
s. Project Design Criteria						
t. Reliability Philosophy						
Execution Approach Elements						
u. Identify Long Lead/Critical Equip. & Matl's						
v. Project Control Requirements						
w. Engineering/Construction Plan & Approach						

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Design/Information Technology Practices

Please place a check to indicate the extent to which each design/information technology application listed below was used on this project. See the legend below for definition of the "Use Levels." If you believe that an application could not have been appropriately applied on this project check "NA."

Use Levels:

1 - Extensive Use	3 - Moderate Use	5 - No Use
2 - Much Use	4 - Little Use	N/A - Not applicable

40a. Was an ***integrated database*** utilized on this project? Yes _____ No ____

If yes, please indicate the extent that each of the following shared data within the integrated database. If other applications were used, please list them. If no, proceed to question 40b.

	Use Levels					
	Extensive Use ←→ No Use					
Applications	1	2	3	4	5	N/A
Facility planning						
Design / Engineering						
3D CAD model						
Procurement / Suppliers						
Material management						
Construction operations / Project controls						
Facility operations						
Administrative / Accounting						

40b. Was ***electronic data interchange (EDI)*** utilized on this project? Yes ___ No ___

If yes, please indicate the extent to which each of the following document types were transmitted using EDI. If other applications were used, please list them. If no, proceed to question 40c.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Applications	Use Levels: Extensive Use ◄──► No Use 1	2	3	4	5	N/A
Purchase orders						
Material releases						
Design specifications						
Inspection reports						
Fund transfers						

40c. Was ***3D CAD modeling*** utilized on this project? Yes ___ No ___

If yes, please indicate the extent to which a 3D CAD model was used for each of the following applications. If other applications were used, please list them. If no, proceed to question 40d.

Applications	Use Levels: Extensive Use ◄──► No Use 1	2	3	4	5	N/A
Define / communicate project scope						
Perform plant walk-throughs (Replacing plastic models)						
Perform plant operability / maintainability analyses						
Perform constructability reviews with design team						
Use as reference during project / coordination meetings						
Work breakdown and estimating						
Plan rigging or crane operations						
Check installation clearances / access						
Plan and sequence construction activities						
Construction simulation / visualization						
Survey control and construction layout						
Material management, tracking, scheduling						
Exchange information with vendors / fabricators						
Track construction progress						
Visualize project details or design changes						
Record "As-Built" conditions						
Train construction personnel						
Safety assessment / training						
Plan temporary structures (formwork, scaffolding, etc.)						
Operation / Maintenance training						
Turn-over design documents to the project owner						
Start-up planning						

CII Benchmarking and Metrics
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40d. Was ***bar coding*** utilized on this project? Yes ____ No ____

If yes, please indicate the extent to which bar coding was used for each of the following applications. If other application were used, please list them. If no, proceed to question 41.

	Use Levels					
	Extensive Use ←→ No Use					
Applications	1	2	3	4	5	N/A
Document control						
Materials management						
Equipment maintenance						
Small tool / consumable material control						
Payroll / Timekeeping						

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Project Change Management Practices

Change Management focuses on recommendations concerning the management and control of both ***scope changes*** and ***project development changes***.

Yes No

41a. ___ ___ Was a formal documented change management process, familiar to the principal project participants used to actively manage changes on this project?

41b. ___ ___ Was a baseline project scope established early in the project and frozen with changes managed against this base?

41c. ___ ___ Were design "freezes" established and communicated once designs were complete?

41d. ___ ___ Were areas susceptible to change identified and evaluated for risk during review of the project design basis?

41e. ___ ___ Were changes on this project evaluated against the business drivers and success criteria for the project?

41f. ___ ___ Were all changes required to go through a formal change justification procedure?

41g. ___ ___ Was authorization for change mandatory before implementation?

41h. ___ ___ Was a system in place to ensure timely communication of change information to the proper disciplines and project participants?

41i. ___ ___ Did project personnel take proactive measures to promptly settle, authorize, and execute change orders on this project?

41j. ___ ___ Did the project contract address criteria for classifying change, personnel authorized to request and approve change, and the basis for adjusting the contract?

41k. ___ ___ Was a tolerance level for changes established and communicated to all project participants?

41l. ___ ___ Were all changes processed through one owner representative?

41m. ___ ___ At project close-out, was an evaluation made of changes and their impact on the project cost and schedule performance for future use as lessons learned?

41n. ___ ___ Was the project organized in a Work Breakdown Structure (WBS) format and quantities assigned to each WBS for control purposes prior to total project budget authorization?

The questionnaire is complete. Thank you for your participation.

Appendix B: BM&M Questionnaire, Version 2 - Contractor

CII Benchmarking and Metrics
Completed Project Data: Contractors (Version 2.0)

The data collected by this form begins the second round of data collection for CII's benchmarking and metrics system. The data will be used to establish performance norms, to identify trends, and to correlate execution of project management processes to project outcomes. It will form part of a permanent database. Through such correlation across many companies and projects, opportunities for improving your company's project performance will be identified. CII will not analyze performance of individual companies, however. Each company will be provided the means to compare itself to the benchmarks. Therefore, it is important that you retain a copy of this questionnaire for your records. **All data will be held in strict confidence.**

When you have completed the questionnaire, please return it to your Company's Data Liaison by **May 1, 1997.**

The next 2 pages contain definitions for project phases. Please pay particular attention to the start and stop points which have been highlighted. All project costs should be given in U.S. dollars. If you need further assistance in interpreting the intent of a question, please call Ned Givens or Kirk Morrow of CII at (512) 471-4319 (E-mail: tkmorrow@mail.utexas.edu). Remember, conformance to the instructions and phase definitions is crucial for establishing reliable benchmarks.

Your company data liaison has been provided with a list of projects which were submitted by your company during the previous data collection effort. In order to maintain the integrity of the database, please ensure that projects which have been submitted previously are not reported again.

If the information required to answer a given question is not available, please write "UNK" (unknown) in the space provided. If the information requested does not apply to this project, please write "NA" (not applicable) in the space provided. However, keep in mind that too many "unknowns" or "not applicables" could render the project unusable for analysis.

This form should be completed under the direction of the project manager. The project manager should consult with colleagues who worked on the project. We urge that you carefully review the phase table on the next 2 pages before attempting to provide the requested information.

Definition is provided in the attached glossary for words and phrases that are both italicized and underlined.

CII Benchmarking and Metrics
Completed Project Data: Contractors (Version 2.0)

Project Phase Table

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Pre-Project Planning Typical Participants: • Owner Personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning Team Personnel Expenses • Consultant Fees & Expenses • Environmental Permitting Costs • Project Manager / Construction Manager Fees • Licensor Costs
Detail Design Typical Participants: • Owner Personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & spec preparation • Bill of material preparation • Procurement Status • Sequence of operations • Technical Review • Definitive Cost Estimate	• Owner Project Management Personnel • Designer Fees • Project Manager / Construction Manager Fees
Demolition / Abatement (see note below) Typical Participants: • Owner Personnel • General Contractor • Demolition Contractor • Remediation / Abatement Contractor	**Start: Mobilization for demolition** **Stop: Completion of demolition**	• Remove existing facility or portion of facility to allow construction or renovation to proceed • Perform cleanup or abatement / remediation	• Owner Project Management Personnel • Project Manager / Construction Manager Fees • General Contractor and/or Demolition Specialist Charges • Abatement / Remediation Contractor Charges

Note: The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not report the demolition / abatement phase if the work is integral with modernization or addition activities.

CII Benchmarking and Metrics
Completed Project Data: Contractors (Version 2.0)

Project Phase Table (Cont.)

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Procurement Typical Participants: • Owner personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Vendor Qualification • Vendor Inquiries • Bid Analysis • Purchasing • Expediting • Engineered Equipment • Transportation • Vendor QA/QC	• Owner project management personnel • Project Manager / Construction Manager fees • Procurement & Expediting personnel • Engineered Equipment • Transportation • Shop QA / QC
Construction Typical Participants: • Owner personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	**Start: Beginning of continuous substantial construction activity** **Stop: *Mechanical Completion***	• Set up trailers • Site preparation • Procurement of bulks • Issue Subcontracts • Construction plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize construction equipment • Warehousing	• Owner project management personnel • Project Manager / Construction Manager fees • Building permits • Inspection QA/QC • Construction labor, equipment & supplies • Bulk materials • Construction equipment • Contractor management personnel • Warranties
Start-up / Commissioning Note: Does not usually apply to infrastructure or building type projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Vendors	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and obtain first Product • Hand-off to user/operator • Operating System • Functional Facility • Warranty Work	• Owner project management personnel • Project Manager / Construction Manager fees • Consultant fees & expenses • Operator training expenses • Wasted feedstocks • Vendor fees

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1. Your Company: ____

2. Your Project I.D. ________________________ (You may use any reference to protect the project's identity. The purpose of this I.D. is to help you and CII personnel identify the questionnaire correctly if clarification of data is needed and to prevent duplicate project entries.)

3. Project Location: Domestic __________________________, USA
State
International _______________________
Country

4. Contact Person (name of the person filling out this form): ____________________

5. Contact Phone No. (   ) __________ **6.** Contact Fax No. (   ) _______________

7. Principal Type of Project (Check only one. If you feel the project does not have a principal type, but is an even mixture of two or more of those listed, please attach a short description of the project. If the project type does not appear in the list, please describe in the space next to "Other."):

Industrial	Infrastructure	Buildings
_______Electrical (Generating)	______Electrical Distribution	______Lowrise Office
_______Oil Exploration/Production	______Highway	______Highrise Office
_______Oil Refining	______Navigation	______Warehouse
_______Pulp and Paper	______Flood Control	______Hospital
_______Chemical Mfg.	______Rail	______Laboratory
_______Environmental	______Water/Wastewater	______School
_______Pharmaceuticals Mfg.	______ Airport	______Prison
_______Metals Refining/Processing	______Tunneling	______Hotel
_______Microelectronics Mfg.	______Marine Facilities	______Maint Facilities
_______Consumer Products Mfg.	______Mining	______Parking Garage
_______Natural Gas Processing		______Retail
_______Automotive Mfg.		
_______Foods		

_______Other (Please describe)____

____

8. This project was (check only one): Grass Roots_____ Modernization _____
Addition _____

Grass roots - a new facility from the foundations and up. A project requiring demolition of an existing facility before new construction begins is also classified as grass roots.

Modernization - a facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility.

Addition - a new addition that ties in to an existing facility, often intended to expand capacity.

_____ Other (Please describe)______________________________

____

9. Please name the Owner of this project. If this information is confidential, please indicate if the owner is a CII member or non-member company. The last page of the glossary contains a CII membership list.

Owner: ____________________________

10. Please indicate in the table below the function(s) **your company** performed on this project and the approximate percent of each to the nearest 10%. For each function, indicate the principle form of remuneration in use at the completion of the work. Also indicate if your contract contained incentives. Use a separate line for each function your company performed.

Please use the following codes to identify the **Function(s)** performed by your company.

PPP	Pre-Project Planner	DM	Demolition/Abatement Contractor
PPC	Pre-Project Planning Consultant	GC	General Contractor
D	Designer	PC	Prime Contractor
PE	Procurement - Equipment	SC	Subcontractor
PB	Procurement - Bulks	PM	Project Manager
		CM	Construction Manager

Percent of Function refers to the percent of the overall function contributed by your company. Estimate to the nearest 10 percent.

Type of Remuneration refers to the overall method of payment. Unit price refers to a price for in place units of work and does not refer to hourly charges for skill categories or time card mark-ups. Hourly rate payment schedules should be categorized as cost reimbursable. Please use the following codes to identify remuneration type.

LS	Lump Sum	CR	Cost Reimbursable/Target Price (Including Incentives)
UP	Unit Price	GP	Guaranteed Maximum Price

If **Incentives** were utilized in your companys' contract, please indicate whether those incentives were positive (a financial incentive for attaining an objective), negative (a financial disincentive for failure to achieve an objective), or both. Circle "+" to indicate a positive incentive and circle "-" to indicate a negative incentive.

Function	Approx. Percent of Function (Nearest 10%)	Type of Remun. (Contract End)	Contract Incentives (circle as many as apply)							
			Cost		Schedule		Safety		Quality	
			+	-	+	-	+	-	+	-
			+	-	+	-	+	-	+	-
			+	-	+	-	+	-	+	-
			+	-	+	-	+	-	+	-
			+	-	+	-	+	-	+	-

10A. Is your company an ***Alliance Partner*** with the owner of this project? Yes ____
No _____

- An alliance partner is a company with whom your company has a long-term formal strategic agreement that ordinarily covers multiple projects.

11a. Your company's *Project Budget at Authorization to Proceed*.

- This is the estimated cost at authorization to proceed for your company's portion of the project only (not the budget for the entire project). If possible, do not include corporate overhead.

- Do not include profit.
- Be sure to include the cost of work performed by your subcontractors.
- **Do not** include the estimated cost of change orders granted while the project was underway (these are examined in question 15)
- State your company's project budget in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

11b. How much ***contingency*** does this budget contain? (to the nearest $1000. You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

12. Your company's *Total Actual Project Cost*:

- This is the actual cost of your company's portion of the project only (not the total cost of the entire project). If possible, do not include corporate overhead.
- Do not include profit.
- **Include** the cost of executing change orders.
- State your companys' Total Actual Project Cost in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

12a. Does the project budget and project cost given above include any general (non-project) corporate overhead?

Yes ______ No ______

13. Please indicate **your company's** budget and actual costs by project phase

- Phase budget amounts should correspond to **your company's budget** at authorization to proceed. Do not include the estimated cost of change orders in the "Phase Budget" column. These are addressed in question 15. However, the "Actual Phase Cost" column should include all project costs, including those attributable to change orders.
- Refer to the table on pages 2 and 3 for phase definitions and typical cost elements.
- Include the cost of bulk materials in construction and the cost of engineered equipment in procurement.
- If your company did not perform any function during a project phase, check "NA" for that phase.
- The sum of phase budgets should equal your company's budget at authorization to proceed and the sum of actual phase costs should equal your company's total actual cost reported in questions 11a & 12 above.)

ProjectPhase	Phase Budget (Including Contingency)	Amount of Contingency in Budget	Actual Phase Cost	NA
Pre-Project Planning	$	$	$	
Detail Design	$	$	$	
Procurement	$	$	$	
Demolition/Abatement	$	$	$	
Construction	$	$	$	
Startup	$	$	$	
Totals	$	$	$	

14. Please indicate **your company's** Planned and Actual Project Schedule

- The dates for the planned schedule should be those in effect when you were authorized to proceed. If you cannot provide an exact day for either the planned or actual, estimate to the nearest week in the form mm/dd/yy; for example, 1/8/96, 2/15/96, or 3/22/96.)
- Refer to the chart on pages 2 and 3 for a description of starting and stopping points for each phase.

- If your company did not perform any function during a project phase, check "NA" for that phase.

Project Phase	Planned Schedule		Actual Schedule		NA
	Start mm / dd / yy	Stop mm / dd / yy	Start mm / dd / yy	Stop mm / dd / yy	
Pre-Project Planning	/ /	/ /	/ /	/ /	
Detail Design	/ /	/ /	/ /	/ /	
Procurement	/ /	/ /	/ /	/ /	
Demolition/Abatement	/ /	/ /	/ /	/ /	
Construction	/ /	/ /	/ /	/ /	
Startup	/ /	/ /	/ /	/ /	

15. ***Project Development Changes*** and ***Scope Changes.*** Please record the changes **to your contract** by phase in the table provided below. For each phase indicate the total number, the **estimated** net cost, and the **estimated** net schedule impact resulting from project development changes and scope changes. The estimates of cost and schedule impact should be those amounts approved by the owner or its agent and incorporated in change orders. Do not include profit. (The actual costs and durations of change orders should be included in your response to questions 12, 13, & 14.)

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis.

Scope Changes include changes in the base scope of work or process basis.

- Changes should be included in the phase in which they were initiated. Refer to the table on pages 2 and 3 to help you decide how to classify the changes by project phase. If you cannot provide the requested change information by phase, but can provide the information for the total project please indicate the totals.

- Write "NA" in the first column for any phase in which your company did not perform work.

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- Indicate "minus" (–) in front of cost or schedule values, if the net changes produced a reduction. If no change orders were granted during a phase, write "0" in the "Total Number" columns.

- State the estimated cost of changes in U.S. dollars to the nearest $1000 and the estimated schedule changes to the nearest week. You may use a "k" to indicate thousands in lieu of "...,000".

Project Phase	Total Number of Project Development Changes	Total Number of Scope Changes	Net Cost Impact of Project Development Changes ($)	Net Cost Impact of Scope Changes ($)	Net Schedule Impact of Project Development Changes (weeks)	Net Schedule Impact of Scope Changes (weeks)
Design			$	$	wks	wks
Procurement			$	$	wks	wks
Demolition/Abatement			$	$	wks	wks
Construction			$	$	wks	wks
Startup			$	$	wks	wks
Totals			$	$	wks	wks

16. Field Rework

Was there a system for tracking and evaluating your company's field rework for this project? Check N/A if your company was not involved in the construction phase.

_____ Yes _____ No _____ N/A

If yes, please complete the following table. If no or N/A, proceed to question 18.

Please indicate the Direct Cost of Field Rework, the Cost of Quality Management, and the Schedule Impact of Field Rework for each category shown in the following table. If you track field rework by a few other or additional categories, please add them in the blank spaces provided. If the system used on this project does not include any of the Sources of Field Rework listed, write "NA" (not applicable) in the Direct Cost of Field Rework space. If your system used a listed Source of Field Rework, but this project had no Field Rework attributable to it, write "0" in the Direct Cost of Field Rework space. If you cannot provide the requested field

rework information by Source of Field Rework, but can provide the information for the total project, please write "UNK" (unknown) in the fields adjacent to the sources of field rework and indicate the totals.

The ***direct cost of field rework*** relates to all costs needed to perform the rework itself whereas the ***cost of quality management*** includes quality assurance or quality control costs, which may identify the need to perform field rework or prevent the need for additional field rework.

Source of Field Rework	Direct Cost of Field Rework	Cost of Quality Management	Schedule Impact of Field Rework
Owner Change	$	$	Weeks
Design Error / Omission	$	$	Weeks
Designer Change	$	$	Weeks
Vendor Error / Omission	$	$	Weeks
Vendor Change	$	$	Weeks
Constructor Error / Omission	$	$	Weeks
Constructor Change	$	$	Weeks
Transportation Error	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
Totals	$	$	Weeks

17. This question is for Owners only.

17b. Project Complexity

Place a mark anywhere on the scale below that best describes the level of complexity for this project as compared to other projects from the same industry sector. For example, if this is a heavy industrial project, how does it compare in complexity to other heavy industrial projects? Use the definitions below the scale as general guidelines.

Low Complexity | Average Complexity | High Complexity

Low Complexity - Characterized by the use of no unproven technology, small number of process steps, small facility size or process capacity, previously used facility configuration or geometry, proven construction methods, etc.

High Complexity - Characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods, etc.

18. Workhours and Accident Data

Please record the total craft workhours, the number of recordable injuries, and the number of lost workday cases for your company and your subcontractors separately in the spaces provided below.

- Use the U.S. Department of Labor's OSHA definitions for recordable injuries and lost workday cases among this project's craft workers. If you do not track in accordance with these definitions, write "UNK" in the recordable injuries and lost workday cases columns.

- Write "UNK" in any space for which the information is unavailable or incomplete. Write "NA" if your company was not involved in the construction phase or provided inspection services only.

- A consolidated project OSHA 200 log is the best source for the data.

	Total Craft Workhours	OSHA Recordable Injuries	OSHA Lost Workday Cases
Your Direct-Hire Craft Employees			
Subcontractor Craft Employees			

18.a. How many of your direct-hire craft employee workhours reported in the table above were "overtime" (or "premium time")? (Write "UNK" in the blank if you don't have this information)

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_______________ hrs

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Safety Practices

Safety includes the site-specific program and efforts to create a project environment and state of consciousness which embraces the concept that all accidents are preventable and that zero accidents is an obtainable goal. If this project was accident free, check "NA" as appropriate for question 27 through 30.

If your company was not involved in the construction phase, go to question 36.

	Yes	No	
19.	___	___	This project had a written site-specific safety plan.
20.	___	___	This project had a written site-specific emergency plan.
21.	___	___	This project had a site safety supervisor.
22.	___	___	The site safety supervisor for this project was full-time.
23.	___	___	This project had a written safety incentive program for hourly craft employees.
24.	___	___	Toolbox safety meetings were required.
25.	___	___	This project required prehire substance abuse testing of contractor employees.
26.	___	___	Contractor employees were randomly screened for alcohol and drugs.

27. Substance abuse tests were conducted after an accident:

_____ Always _____ Sometimes _____ Seldom _____ Never ___ NA

28. Accidents were formally investigated:

_____ Always _____ Sometimes _____ Seldom _____ Never ___ NA

29. Near-misses were formally investigated:

_____ Always _____ Sometimes _____ Seldom _____ Never ___ NA

30. Senior management reviewed accidents:

_____ Always _____ Sometimes _____ Seldom _____ Never ___ NA

31. Safety was a high priority topic at all pre-construction and construction meetings:

_____ Always _____ Sometimes _____ Seldom _____ Never

32. Safety records were a criterion for contractor/subcontractor selection:

_____ Always _____ Sometimes _____ Seldom _____ Never

33. Pre-task planning for safety was conducted by contractor foremen:

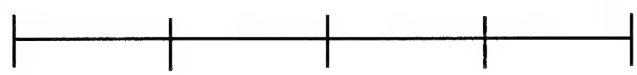
_____ Always _____ Sometimes _____ Seldom _____ Never

34. Jobsite-specific orientation was conducted for new contractor and subcontractor employees:

_____ Always _____ Sometimes _____ Seldom _____ Never

35. Place a mark anywhere on the scale below that best describes the owner's commitment to safety on this project. Judge this owner's commitment relative to that of owners that you have experience with.

Low High



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Team Building Practices

Team Building is a process that brings together a diverse group of project participants and seeks to resolve differences, remove roadblocks and proactively build and develop the group into an aligned, focused and motivated work team that strives for a common mission and for shared goals, objectives and priorities.

36. Was your company involved in a team building process that included owner personnel on this project?

Yes ____ No ____

If yes, answer questions 36a - 36h. If no, go to question 37.

	Yes	No	
36a.	___	___	Was an independent consultant used to facilitate the team building process?
36b.	___	___	Was a team-building retreat held early in the life of the project?
36c.	___	___	Did this project have a documented team-building implementation plan?
36d.	___	___	Were objectives of the team building process documented and clearly defined?

36e. Were team building meetings held among team members throughout the project?

______ Regularly ______ Sometimes ______ Seldom ______ Never

36f. Were follow-up sessions held to integrate new team members and reinforce concepts?

______ Regularly ______ Sometimes ______ Seldom ______ Never

36g. Please indicate the project phases in which your company was involved in the team building process? (Check all that apply)

____ Pre-Project Planning
____ Design
____ Procurement
____ Construction
____ Startup

36h. Please indicate the parties involved in the team building process? (Check all that apply)

____ Owner
____ Designer(s)
____ Contractor(s)
____ Major Suppliers
____ Subcontractor(s)
____ Construction Manager
____ Other. If other, please specify ______________________________

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Constructability Practices

Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Constructability is achieved through the effective and timely integration of construction input into planning and design as well as field operations. If your company was not involved in the constructability process check "Unknown."

37. Was Constructability implemented on this project? Yes ____ No _____ Unknown _

If yes, please respond to the following statements (37a-37l). If no or unknown, go to question 38.

37a. Which of the following best describes the constructability program designation for this project?

____ No designation
____ Part of standard construction management activities
____ Part of another program, such as Quality or only identified on a project level
____ Recognized on a corporate level, but may be part of another program
____ Stand-alone program on same level as Quality or Safety

37b. Which of the following best describes the constructability training of personnel for this project?

____ None
____ If any occurs, done as on-the-job training
____ Awareness seminar(s)
____ Part of standard orientation
____ Part of standard orientation; deeply ingrained in corporate culture

37c. Which of the following best describes the role of the constructability coordinator for this project?

____ Coordinator not identified
____ Part-time if identified; very limited responsibility
____ Informal full- or part-time position; responsibilities vary
____ Formal full- or part-time position; responsibilities vary
____ Full-time position; plays major project role

37d. Which of the following best describes the constructability program documentation for this project?

____ None; CII documents may be available
____ Limited reference in any manual; CII documents may be distributed or referenced
____ Project-level constructability documents exist; may be included in other corporate documents
____ Project constructability manual is available
____ Project constructability manual is thorough, widely distributed, and periodically updated

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project?

____ None
____ Reactive approach, constrained by review mentality, poor understanding of proactive benefit
____ Aware of major benefits, proactive approach
____ Proactive approach; routinely consult lessons learned
____ Aggressive, proactive approach from beginning of project; routinely consult lessons learned

37f. Which of the following best describes the implementation of constructability concepts on this project?

____ Very little concept implementation
____ Some concepts used periodically; often considered too late to be of use
____ Selected concepts applied regularly; full use, timeliness of input varies
____ All concepts consistently considered; timely implementation of feasible concepts
____ All concepts consistently considered, continuously evaluated, aggressively implemented

37g. Constructability ideas on this project were collected by: (Check as many as apply)

_____ Suggestion Box
_____ Interviews
_____ Review Meetings
_____ Questionnaire
_____ Other Methods ____

_____ Not Collected

37h. To what extent was a computerized constructability database utilized for this project?

_____ None
_____ Minimal
_____ Moderate
_____ Extensive

37i. Please characterize the frequency of the constructability reviews and discussions for this project.

_____ Once a Week
_____ Once a Month
_____ Once every 3 Months
_____ Once every 6 Months
_____ Once a Year or Less Frequent

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability. Place a check below the appropriate period.

Pre-Project Planning			Detail Design/Procurement			Construction		
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late

Yes No

37k. ___ ___ Constructability was an element addressed in this project's formal written execution plan.

37l. ___ ___ Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?

If yes, please list? $ ________________

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Pre-Project Planning Practices

Pre-Project Planning involves the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning.

38. Did your company participate in the pre-project planning effort? (Check only one of 38a, 38b, or 38c)

38a. ___ Yes, as the pre-project planner. Please continue with question 38d.

38b. ___ Yes, as a consultant (to the owner or to another firm that performed pre-project planning for the owner). Please continue with question 38d.

38c. ___ No, my company did not participate in the pre-project planning. Go to question 39.

38d. Did your company formally assess the quality of the pre-project planning effort?

Yes ______ No _____

Please respond to the following statements using the definitions provided below the scale for guidance.

38e. Place a mark on the scale below that best describes the composition of the pre-project planning team.

Excellent Poor

|----|----|----|----|

Excellent - Highly skilled and experienced members with authority; representation from business, project management, technical disciplines, and operations; able to respond to both business and project objectives.

Poor - Members with a poor combination of skill or experience that lack authority; insufficient representation from business, project management,

technical disciplines, and operations; unable to respond to both business and project objectives.

38f. Place a mark on the scale below that best describes the technology evaluation for this project.

Excellent Poor

Excellent - Thorough and detailed identification and analysis of existing and emerging technologies for feasibility and compatibility with corporate business and operations objectives. Scale-up problems and hands-on process experience were considered.

Poor - Poor or no technology evaluation.

38g. Place a mark on the scale below that best describes the evaluation of alternate siting locations.

Excellent Poor

Excellent - Thorough and detailed assessment of relative strengths and weaknesses of alternate locations to meet owner requirements.

Poor - Poor or no evaluation of alternate siting locations.

38h. Place a mark on the scale below that best describes the risk analysis performed for project alternatives.

Excellent Poor

Excellent - Risks associated with the selected project alternatives were identified and analyzed. These analyses included financial/business, regulatory, project, and operational risk categories in order to minimize the impacts of risks on project success.

Poor - Poor or no risk analysis performed for project alternatives.

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The Project Definition Rating Index (PDRI) identifies and describes critical elements in a scope definition package and allows a project team to predict factors impacting project risk. It is intended to evaluate the completeness of project scope definition prior to consideration for authorization.

39. Was the Project Definition Rating Index (PDRI) utilized on this project? _____ yes _____ no

If yes, indicate the score received just prior to total project budget authorization.

____

Please attach a copy of the PDRI scoresheet and proceed to question 40.

If no, please complete the matrix on the following page.

Please complete the following matrix using the appropriate definition levels given below. Definition is provided for each of the pre-project planning elements on pages 4 through 11 of the glossary of terms. Indicate how well defined each element was prior to the total project budget authorization by placing a check below the appropriate definition level. Elements with definition levels 2 through 4 darkened should be answered as "yes/no" questions. Indicate definition level 1 for "yes" or definition level 5 for "no" to indicate if the elements either existed or did not exist within the project definition package at authorization.

Definition Levels:

1 - Complete definition	3 - Some deficiencies	5 - Incomplete or poor definition
2 - Minor deficiencies	4 - Major deficiencies	N/A - Not applicable

Note: If the project on which you are reporting is a building or infrastructure project, some of the following elements may not apply to your project. Please place a check in the "N/A" column to indicate "not applicable" if any element does not apply to your project.

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	Definition Level at Authorization					
	Complete ←→ Poor					
Technical Elements	1	2	3	4	5	N/A
a. Process Flow Sheets						
b. Site Location		[redacted]				
c. P&ID's						
d. Heat & Material Balances						
e. Environmental Assessment						
f. Utility Sources With Supply Conditions						
g. Mechanical Equipment List						
h. Specifications - Process/Mechanical						
i. Plot Plan						
j. Equipment Status						
Business Elements						
k. Products						
l. Capacities						
m. Technology						
n. Processes						
o. Site Characteristics Available vs. Req'rd		[redacted]				
p. Market Strategy						
q. Project Objectives Statement		[redacted]				
r. Project Strategy						
s. Project Design Criteria						
t. Reliability Philosophy						
Execution Approach Elements						
u. Identify Long Lead/Critical Equip. & Matl's						
v. Project Control Requirements						
w. Engineering/Construction Plan & Approach						

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Design/Information Technology Practices

Please place a check to indicate the extent to which each design/information technology application listed below was used on this project. See the legend below for definition of the "Use Levels." If you believe that an application could not have been appropriately applied on this project check "N/A." If your company was not involved with the project function(s) in which an application is generally used, please check "Unk" for that application.

Use Levels:
1 - Extensive Use 3 - Moderate Use 5 - No Use Unk - Unknown
2 - Much Use 4 - Little Use N/A - Not applicable

40a. Was an ***integrated database*** utilized on this project? Yes ___ No ___ Unk ___

If yes, please indicate the extent that each of the following shared data within the integrated database. If other applications were used, please list them. If no, proceed to question 40b.

	Use Levels						
	Extensive Use ←			→ No Use			
Applications	1	2	3	4	5	N/A	Unk
Facility planning							
Design / Engineering							
3D CAD model							
Procurement / Suppliers							
Material management							
Construction operations / Project controls							
Facility operations							
Administrative / Accounting							

40b. Was ***electronic data interchange (EDI)*** utilized on this project? Yes ___ No ___

Unk ___

If yes, please indicate the extent to which each of the following document types were transmitted using EDI. If other applications were used, please list them. If no, proceed to question 40c.

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	Use Levels						
	Extensive Use ←				→ No Use		
Applications	1	2	3	4	5	N/A	Unk
Purchase orders							
Material releases							
Design specifications							
Inspection reports							
Fund transfers							

40c. Was ***3D CAD modeling*** utilized on this project? Yes ____ No ____ Unk____

If yes, please indicate the extent to which a 3D CAD model was used for each of the following applications. If other applications were used, please list them. If no, proceed to question 40d.

	Use Levels						
	Extensive Use ←				→ No Use		
Applications	1	2	3	4	5	N/A	Unk
Define / communicate project scope							
Perform plant walk-throughs (Replacing plastic models)							
Perform plant operability / maintainability analyses							
Perform constructability reviews with design team							
Use as reference during project / coordination meetings							
Work breakdown and estimating							
Plan rigging or crane operations							
Check installation clearances / access							
Plan and sequence construction activities							
Construction simulation / visualization							
Survey control and construction layout							
Material management, tracking, scheduling							
Exchange information with vendors / fabricators							
Track construction progress							
Visualize project details or design changes							
Record "As-Built" conditions							
Train construction personnel							
Safety assessment / training							
Plan temporary structures (formwork, scaffolding, etc.)							
Operation / Maintenance training							
Turn-over design documents to the project owner							
Start-up planning							

40d. Was ***bar coding*** utilized on this project? Yes ____No ____ Unk ____

If yes, please indicate the extent to which bar coding was used for each of the following applications. If other application were used, please list them. If no, proceed to question 41.

	Use Levels						
	Extensive Use ←				→ No Use		
Applications	1	2	3	4	5	N/A	Unk
Document control							
Materials management							
Equipment maintenance							
Small tool / consumable material control							
Payroll / Timekeeping							

CII Benchmarking and Metrics
Completed Project Data: Contractors (Version 2.0)

Project Change Management Practices

Change Management focuses on recommendations concerning the management and control of both ***scope changes*** and ***project development changes***. If your company was not involved with the project function(s) in which a practice element is generally used, please write "UNK" for that question.

Yes No

41a. ___ ___ Was a formal documented change management process, familiar to the principal project participants used to actively manage changes on this project?

41b. ___ ___ Was a baseline project scope established early in the project and frozen with changes managed against this base?

41c. ___ ___ Were design "freezes" established and communicated once designs were complete?

41d. ___ ___ Were areas susceptible to change identified and evaluated for risk during review of the project design basis?

41e. ___ ___ Were changes on this project evaluated against the business drivers and success criteria for the project?

41f. ___ ___ Were all changes required to go through a formal change justification procedure?

41g. ___ ___ Was authorization for change mandatory before implementation?

41h. ___ ___ Was a system in place to ensure timely communication of change information to the proper disciplines and project participants?

41i. ___ ___ Did project personnel take proactive measures to promptly settle, authorize, and execute change orders on this project?

41j. ___ ___ Did the project contract address criteria for classifying change, personnel authorized to request and approve change, and the basis for adjusting the contract?

41k. ___ ___ Was a tolerance level for changes established and communicated to all project participants?

41l. ___ ___ Were all changes processed through one owner representative?

41m. ___ ___ At project close-out, was an evaluation made of changes and their impact on the project cost and schedule performance for future use as lessons learned?

41n. ___ ___ Was the project organized in a Work Breakdown Structure (WBS) format and quantities assigned to each WBS for control purposes prior to total project budget authorization?

The questionnaire is complete. Thank you for your participation.

Appendix C: Best Practice Indices Calculations

CONSTRUCTABILITY PRACTICE USE

Question	Yes	No
37. Was Constructability implemented on this project?	X	

37a. Which of the following best describes the constructability program designation for this project? (Choose one)	
0.00	No designation
0.25	Part of standard construction management activities
0.50	Part of another program, such as Quality or only identified on a project level
0.75	Recognized on a corporate level, but may be part of another program
1.00	Stand-alone program on same level as Quality or Safety

Score
0.25

37b. Which of the following best describes the constructability training of personnel for this project? (Choose one)	
0.00	None
0.25	If any occurs, done as on-the-job training
0.50	Awareness seminar(s)
0.75	Part of standard orientation
1.00	Part of standard orientation; deeply ingrained in corporate culture

Score
0.25

37c. Which of the following best describes the role of the constructability coordinator for this project? (Choose one)	
0.00	Coordinator not identified
0.25	Part-time if identified; very limited responsibility
0.50	Informal full- or part-time position; responsibilities vary
0.75	Formal full- or part-time position; responsibilities vary
1.00	Full-time position; plays major project role

Score
0.50

37d. Which of the following best describes the constructability program documentation for this project? (Choose one)	
0.00	None; CII documents may be available
0.25	Limited reference in any manual; CII documents may be distributed or referenced
0.50	Project-level constructability documents exist; may be included in other corporate documents
0.75	Project constructability manual is available
1.00	Project constructability manual is thorough, widely distributed, and periodically updated

Score
0.00

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project? (Choose one)	
0.00	None
0.25	Reactive approach, constrained by review mentality, poor understanding of proactive benefit
0.50	Aware of major benefits, proactive approach
0.75	Proactive approach; routinely consult lessons learned
1.00	Aggressive, proactive approach from beginning of project; routinely consult lessons learned

Score
0.50

37f. Which of the following best describes the implementation of constructability concepts on this project? (Choose one)	
0.00	Very little concept implementation
0.25	Some concepts used periodically; often considered too late to be of use
0.50	Selected concepts applied regularly; full use, timeliness of input varies
0.75	All concepts consistently considered; timely implementation of feasible concepts
1.00	All concepts consistently considered, continuously evaluated, aggressively implemented

Score
0.50

37g. Constructability ideas on this project were collected by: (As many as applicable)

		Score
0.10	Suggestion Box	
0.20	Interviews	0.20
0.40	Review Meetings	0.40
0.20	Questionnaire	
0.10	Other Methods	

37h. To what extent was a computerized constructability database utilized for this project? (Choose one)

0.00	None
0.33	Minimal
0.67	Moderate
1.00	Extensive

Score
0.33

37i. Please characterize the frequency of the constructability reviews and discussions for this project. (Choose one)

1.00	Once a Week
0.75	Once a Month
0.50	Once every 3 Months
0.25	Once every 6 Months
0.00	Once a Year or Less Frequent

Score
0.75

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability. (Choose one)

1.00	Early Pre-Project Planning
0.90	Middle Pre-Project Planning
0.80	Late Pre-Project Planning
0.70	Early Detail Design/Procurement
0.60	Middle Detail Design/Procurement
0.50	Late Detail Design/Procurement
0.20	Early Construction
0.10	Middle Construction
0.00	Late Construction

Score
0.90

Question	**Yes**	**No**	**Score**
37k. Constructability was an element addressed in this project's formal written execution plan.	1.00	0.00	1.00
37l. Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?	1.00	0.00	0.00

TOTAL	5.58
12 Questions, Maximum Score of 12 ⇒ Divide total by 1.2 to scale to 1-10 point range	
Constructability Practice Use Index	**4.65**

PRE-PROJECT PLANNING PRACTICE USE

Question 38	Excellent = 10 — Poor = 0	Score
Place a mark on the scale that best describes:		
38e. The composition of the Rre-Project Planning team.	X	7.5
38f. The technology evaluation for this project.	X	5.0
38g. The evaluation of alternate siting locations.	NA	10.0
38h. The risk analysis performed for project alternatives	X	2.5

TOTAL	25.0
Maximum Score of 40 ⇒ Divide total by 4 to scale to 1-10 point range	6.25
Divide scaled total by 2 ⇒ Question 38 represents half the Pre-Project Planning Use Index	3.13

Question 39		Use Levels: Extensive Use				No Use		
Technical Elements		1	2	3	4	5	N/A	**Score**
a.	Process Flow Sheets	36	26	17	8	2	0	26
b.	Site Location	32	[redacted]			2	0	32
c.	P&ID's	31	23	15	8	2	0	23
d.	Heat & Material Balances	23	17	10	5	1	0	17
e.	Environmental Assessment	21	15	10	5	2	0	10
f.	Utility Sources With Supply Conditions	18	12	8	4	1	0	18
g.	Mechanical Equipment List	18	13	9	4	1	0	13
h.	Specifications - Process/Mechanical	17	12	8	4	1	0	8
i.	Plot Plan	17	13	8	4	1	0	17
j.	Equipment Status	16	12	8	4	1	0	12

Business Elements								
k.	Products	56	33	22	11	1	0	33
l.	Capacities	55	33	21	11	2	0	55
m.	Technology	54	39	21	10	2	0	54
n.	Processes	40	28	17	8	2	0	40
o.	Site Characteristics Available vs. Req'rd	29	[redacted]			2	0	29
p.	Market Strategy	26	16	10	5	2	0	16
q.	Project Objectives Statement	25	[redacted]			2	0	25
r.	Project Strategy	23	14	9	5	1	0	14
s.	Project Design Criteria	22	16	11	6	3	0	11
t.	Reliability Philosophy	20	14	9	5	1	0	9
Execution Approach Elements								
u.	Identify Long Lead/Critical Equip & Matl's	8	6	4	2	1	0	6
v.	Project Control Requirements	8	6	4	2	0	0	6
w.	Engineering/Construction Plan & Approach	11	8	5	3	1	0	11

TOTAL (Question 39)	485
Maximum Score of 606 ⇒ Divide total by 60.6 to scale to 1-10 point range	8.00
Divide scaled total by 2 ⇒ Question 39 represent half the Pre-Project Planning Practice Use Index	4.00

Sum Question 38 and Question 39 modified totals	
Pre-Project Planning Practice Use Index	**7.13**

TEAM BUILDING PRACTICE USE

Question	Yes	No	Score
36. Was a team building process used for this project?	1.00	0.00	1.00
36a. Was an independent consultant used to facilitate the team building process?	1.00	0.00	0.00
36b. Was a team-building retreat held early in the life of the project?	1.00	0.00	1.00
36c. Did this project have a documented team-building implementation plan?	100	0.00	0.00
36d. Were objectives of the team building process documented and clearly defined?	1.00	0.00	0.00

Question	Regularly	Sometimes	Seldom	Never	Score
36e. Were team building meetings held among team members throughout the project?	1.00	0.67	0.33	0.00	0.33
36f. Were follow-up sessions held to integrate new team members and reinforce concepts?	1.00	0.67	0.33	0.00	0.00

36g. Please indicate the project phases in which team building was used.

Pre-Project Planning	Design	Procurement	Construction	Startup	Score
0.30	0.30	0.10	0.20	0.10	0.20

36h. Please indicate the parties involved in the team building process.

Owner	Designer	Contractors	Major Suppliers	Subs	Constr. Mngr.	Other	Score
0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.286

TOTAL	2.82
8 Questions, Maximum Score of 8 ⇒ Divide total by 0.8 to scale to 1-10 point range	
Team Building Practice Use Index	**3.52**

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Vita

Michael Deen Miller was born in Lafayette, Indiana on May 13, 1972, the son of Jacquline Sargent Miller and Roy Deen Miller. After graduating from Edgewood High School, Edgewood, Maryland, in 1990, Michael accepted a presidential nomination to the United States Air Force Academy in Colorado Springs, Colorado. While there, Michael was a four-year letterman on the Air Force Academy Lacrosse Team; being awarded a Western Athletic Conference Scholar Athlete Award in 1993 and selected to the Great Western League All-Star Lacrosse Team in the position of Long Stick Midfield in 1994. He received his Bachelor of Science degree in Civil Engineering from the Air Force Academy in June 1994. Upon graduation he was commissioned a second lieutenant in the United States Air Force and assigned to McGuire Air Force Base in Wrightstown, New Jersey. He served three years at McGuire as a Civil Engineer Officer managing base facility design and construction contracts and family housing maintenance. In 1997, he was selected by the Air Force to continue his education by pursuing a graduate degree in construction engineering and project management from a civilian institute. He entered The Graduate School of The University of Texas in August 1997.

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